TRANSACTIONS
OF THE
INSTITUTION
OF
CIVIL ENGINEERS

VOL. III. PART I.

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VOLUME III.—PART I.

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TRANSACTIONS.

I.—*On Steam-Boilers and Steam-Engines.*

By JOSIAH PARKES, M.Inst.C.E.

In a former paper* "On the Evaporation of Water from Steam-boilers," I laid before the Institution several tables shewing the evaporative product of three distinct classes of boiler in common practice; with remarks elucidating various phenomena which attend combustion, and the treatment of fuel. I now propose to investigate and compare the peculiar properties of those and other boilers, as exemplified in their practice; to show their points of agreement and disagreement; to exhibit their respective merits and demerits as evaporative vessels; to point out some general laws which may contribute to give greater uniformity to the results of evaporation from any assigned heated surface of boiler, and enable the employer of a boiler, not only to ascertain if he is using his fuel economically or wastefully, but to apply a remedy should he find his practice imperfect.

I stated, in the paper referred to, that "had we a full knowledge of the relative strength of the coals employed, and full information of the respective areas of the grates, and of the heated surface of the boilers, an investigation into the *causes* of the superiority of one boiler over another, both as regards their *evaporative power* and *evaporative economy*, might be instructively, if not successfully entered upon." The tables in that paper give the amount of evaporation, the weight of fuel consumed, and the temperature of the water entering a

* Transactions of the Inst. C. E. Vol. II.

variety of boilers; by further tabulating the dimensions of the several boilers, the area of their grates, the area of their heat-absorbing surfaces, with the rates of combustion and evaporation, we have every element for the proposed investigation and comparison, excepting one, viz. the relative strength of the coals employed. This is a deficiency which cannot be supplied, but the absence of that knowledge—interesting and useful as it would be—will not be found to affect those general principles which conduce to the economy, durability, and safety of steam-boilers, principles which depend on the construction and proportion of the vessels to the work required of them, combined with their management and the application of the heat.

Evaporation is the measure of the *useful effect* obtained from any given weight of fuel of any kind. By comparing, therefore, the product from one boiler with that from another, and by observing the results of different modes of practice on the same boiler, the value of any arrangement of the parts of an evaporative vessel, with its fitness for its intended purpose, can be ascertained. For the sake of clearness, I shall confine my remarks on the steam-boilers under review to Part I. of this paper, so far as regards the elucidation of their qualities, and performance as evaporative vessels, their general management, and the phenomena attending the combustion of the fuel.

Evaporation, when combined with the knowledge of the duty done by an engine, is also the measure of the *useful effect* of a given weight of water in the shape of steam, as an agent of mechanical power; and it furnishes the only true test of the value of different systems of applying steam. Were we ignorant of all the other properties of steam besides those of its elasticity, its expansiveness, and its condensibility, we could still—if acquainted with the weight of water which, in the shape of steam, has passed from the boiler through the cylinder of an engine, and produced a certain effect—arrive at a practical and precise determination of the efficiency of that steam as a motive force, and of the relative excellences of different engines.

During the infancy of the steam-engine the quantity of water, as steam, necessary to produce a given effect or *duty,* was as much the object of consideration by the chief improvers of the engine, as the quantity of coal consumed. It formed the subject of continual trial and laborious study, both experimentally and practically, by Smeaton, and it was the basis of Watt's discoveries. Smeaton, with his characteristic accuracy of detail, has recorded the particulars of the boilers, evaporation, consumption of fuel, and duty of the Long Benton

engine, which was the model, and may be called the gauge of the performance of the best engines on the atmospheric principle. I have transferred the particulars of these boilers and engine to the ensuing tables, not only as interesting matters of history, but as useful evaporative and comparative facts.

I am acquainted with no other recorded trial of the whole quantity of steam passing through Watt's double engine than that made by himself and Rennie, at the Albion Mills; I have also extracted these particulars, and tabulated them as affording a specimen of that which was considered by Watt himself as the full performance of his rotative engine. The duty done by the engine at the Albion Mills, as estimated by the quantity of *steam* used, has probably not been exceeded by any one of the same unexpansive kind since constructed by Watt, or other makers, though in a few instances less *coal* may have been consumed through more skilful management, and the use of better boilers.

The bushel of coal was originally fixed by Watt as the measure of the duty done by the pumping engine. It was presumed that the engine which consumed the least coal, required the least steam, and doubtless, on the aggregate of engines of the same class having similar proportions of parts and boiler, and using the same kind of coal, this would be true. For commercial purposes, also, when the maker was paid, as Watt originally was, a certain share of the saving in coals which he effected over other engines, the weight or measure of fuel burnt, compared with its effect, formed the most convenient criterion of the merit of the engine between its maker and its employer. Hence originated the denomination of duty, as the weight of water raised one foot by a bushel of coal. The constant association of this standard in the minds of engineers, has probably been the cause that, notwithstanding the progressive improvements in the performance of pumping engines, in Cornwall especially, we have remained in utter ignorance of the progressive diminution in their consumption of *steam*. From neglecting to determine this indispensable datum, it has chiefly arisen that the reports of the Cornish engineers, as to the duty done by the modern high pressure expansive engines, have been so long either discredited or doubted. A loophole has been left for disbelief, by their referring, from fixed habit, to an *uncertain*, rather than to a *certain* standard of comparison, and though in a district of England where every engineer, and every employer of an engine, (persons the most interested in ascertaining, and the most capable of determining, and profiting by the truth,) have been for years satisfied as to the preeminent superiority of the high pressure expansive over Watt's low pressure engine, never-

theless, strong assertion has never been idle beyond the confines of that district, in attributing the reported difference in the performance of these two engines, to a false or incorrect mode of taking the duty, to some miraculous strength of the coals employed, or to some mysterious and unexplained fertility of steam in the Cornish boiler. On the other hand, the advocates of the high pressure expansive system may, from the same want of positive data, have somewhat exaggerated the dynamic advantage derivable from that method of employing steam.

Mr. Wicksteed*, by his admirable *experimentum crucis*, viz., the weighing of the water actually raised by a bushel of coals, has demonstrated the near coincidence of the Cornish system of ascertaining the duty with the real performance of the engine. Still, the knowledge of the steam consumed in doing the duty, remained to be unfolded. This I have at length the means of developing from experiments on two Cornish engines, which will establish that boiler and engine in their true situation in the scale of economy. These, with similar facts, indicated by a knowledge of the evaporation and duty of several other classes of engines, I propose to consider separately in a second part of this paper.

PART I.

ON THE QUALITIES OF STEAM-BOILERS, AND ON THE INFLUENCE EXERCISED OVER EVAPORATION BY THEIR PROPORTIONS AND PRACTICAL MANAGEMENT.

My own experiments on these subjects commenced more than twenty years since, and I fortunately preserved, in each instance, the particulars of the dimensions of the boilers and grates operated upon. I very early perceived that the *completeness*, and the *rate* of combustion, were important elements in evaporative economy, and also that the *proportion of the grates* to the combustion effected upon them, as well as to the whole heat-absorbing surface, exercised a considerable influence over the results; nor could I fail to observe that the greatest results were obtained when these elements bore some certain ratio to each other. Still I did not consider that the amount of my experience, or the number of my experiments, operating as I did, on one form of boiler alone, (the *wagon*,) justified the laying down a rule which could be common to all the possible forms of boiler It appeared to me that the boiling apparatus of a steam-engine was

* Trans. Inst. C. E. Vol. II.

capable of being thrown into an infinite variety of shapes; that the combustion of the fuel might be employed at an intensity far exceeding that in the then common practice; and I thought it very possible that some strange shape and condition of boiler might be invented, which would set a limit to practice in rapid combustion, whilst I considered my own practice at Warwick to have reached very nearly the extreme of slow combustion. I also thought that varieties of boilers, or systems of practice might be introduced, which would serve as intermediate specimens, and connect the two extremes. Time has justified these expectations, and by this delay I have avoided falling into the too common error of generalizing from insufficient data, or isolated facts,—an error productive of much mischief to the progress of science, as the reputation of an author, coupled with the indisposition of the mass of men to think for themselves, frequently occasion very imperfect, and even erroneous doctrines to be received as law. It is not till facts, unexceptionable in their nature, and multiplied in number, stand forth in all the clearness of truth, that the theory of their action can be investigated with certainty and success.

To my own experiments * detailed in my former paper on wagon boilers, I have now added Smeaton's at the Long Benton, and Watt's at the Albion Mills engines.

Since the period referred to, the *locomotive* engine has sprung into being, and its boiler has taken a place so important as an evaporative vessel, that to an enquirer on this subject it is full of interest. It touches the margin of the highest possible intensity of combustion in its use of fuel; it exceeds all other boilers in evaporative power, and presents in its various properties, contrasts so striking with every other class of boiler, that the analysis of its properties and effects is eminently instructive. M. de Pambour having recorded the full particulars of the boilers and grates belonging to the engines on which he experimented, I am able to examine them in reference to their qualities and evaporation, of which I gave a table in my former paper.

To this class I have now added Mr. Wood's experiments on the boiler of an engine detailed in the third edition of his Work on Railways, page 333.

The evaporative qualities of the *Cornish* boiler have been but little enquired into. This particular form of boiler, long established as it has been in a district

* The term *experiment* is used throughout this paper in the sense of an *observation of facts* attending the common every day working of the boilers, except in a few cases which are specially mentioned.

of England to which high pressure steam used expansively has been pretty much confined, and which has there supplanted all other forms as the best adapted for its purpose, is the more interesting, and the more worthy of investigation, from its forming part of a system of generating and employing steam, the economy of which has been silently, slowly, but surely progressive. A fair test of its effects as compared with other boilers will be found supplied in Table IV. of my former paper, and having since obtained the measurement of the boilers and grates appertaining to the experiments therein recorded, I am now enabled to furnish and to analyse all the principles on which those effects depend.

In addition to these I have tabulated the particulars of two other boilers whose surfaces and consumption of fuel are stated in Mr. Henwood's paper of last session, as they serve, even without a knowledge of their evaporation, (which unfortunately does not accompany them,) to determine the proportions of boilers, and other useful data connected with the practice of the Cornish engineers.

The *marine* boiler is another distinctive class as regards structure, and arrangement of parts. These it has gradually assumed by the apparently common consent, and from the united experience of marine engine makers; it may therefore be supposed to combine the peculiar characteristics which fit it in their judgment for the locality and circumstances of a steam-vessel,—these require that the boiler should possess, in a preeminent degree, the three prime qualities of safety, durability, and economy, together with an abundant evaporative power. I greatly regret that I have no data by which to compare its properties and practical results in the generation of steam with other boilers, as I cannot meet with any authenticated experiments on its evaporative qualities in actual work on sea or rivers. Such experiments would be invaluable to the marine engineer, as demonstrative of the economy of his boiler in the use of fuel, a quality of first rate and growing consequence to steam navigation, and I need scarcely repeat that an acquaintance with the evaporation is the only sure test of the respective value of different kinds of fuel. The marine boiler is also beginning to be used in lieu of the common wagon boiler, and as there seems no reason why it should be unsuitable to a fixed engine, or other steam work employing steam at a very moderate pressure, provided the evaporative economy and durability of the two boilers are equal, it is to be regretted that its powers have not been tested, or if tested, not published *.

* It would require much care and experimental tact to make sufficiently exact trials of the evaporation produced from marine boilers on board *steam-vessels*. Evaporative experiments of short dura-

A variety of this class was brought under the notice of the Institution last session by Mr. Manby, in a paper on Collier's Patent Boiler. There is also recorded in Mr. Wood's Work on Railways, first edition, an experiment on a marine boiler with captain Ericson's fanning apparatus. It forms, however, no part of my plan to investigate the properties of these inventions; nor is it my province or desire to pronounce on the value of them, nor on that of numerous other ingenious contrivances for economizing fuel, which are to be found in partial use, or accounts of which are scattered in various publications. My motives in undertaking the present task have been to collect and make known authentic facts on the working of boilers and engines of established credit and notoriety, and so to exhibit them as to enable the employer of any boiler or engine, whether similar or dissimilar, to compare his practice with specimens of acknowledged and well attested merit.

The following Table is formed from the data referred to in my paper of last session with the additions above mentioned. By elimination, the relation or ratio which any one property or effect of the boilers bears to another is shewn; and the arrangement of the Table is such that each succeeding column or set of columns may be said to form links in the chain of evidence which terminate in the disclosure of the objects sought, viz. the principal conditions upon which evaporative economy is dependent.—Vide Table at the end of this paper.

Table I. From this Table, which presents a collective and digested view of all the experiments; of the relation which the several parts of the boilers bear to one another, and to the effects produced; of the amount and activity of the combustion, which may be termed the *calorific forces* to which boilers are exposed; as also of the modifications which these forces undergo through the structure and disposition of the several parts,—I shall select and place at the head of my observations on each class of boiler, those quantities and qualities which point themselves out as exerting the chief influence over the results. These sums are exponential of the practice, and of its effects, and they truly represent the relative calorific forces to which the several boilers are subject, and

tion on any boilers are of little practical value, and they require to be closely superintended by men accustomed to accurate observation. The necessity of frequently *blowing out*, or otherwise cleansing marine boilers, whether at work in sea or in rivers, would render such experiments very inconclusive, and most of these boilers are more liable to the *disease* of *priming* than any other class. Experiments, however, quite free from error, and of much value to the marine engineer, may be conducted on such boilers when supplying a fixed engine.

upon the degree of whose intensity and duration, the economy, durability, and safety of evaporative vessels must mainly depend.

I have reserved for separate examination, at the end of this paper, the question of the influence of *time* in producing the relative degrees of economy, as it requires special and careful analysis before a satisfactory determination of the value of that element can be arrived at. By *time*, I mean the relative periods of the duration of a given amount of heat about the boilers, and about equal areas of their surface. The facts arising out of this investigation will be found classified in Tables 3 and 5, whence they are transferred to Table 1.

Uniformity in the gradation of results from any one cause cannot be expected in a series of experiments on boilers of such various structure and strength of materials, but it will be apparent, from a single glance over the columns, that the rate of combustion, and its rate on each square foot of grate, very sensibly affect them; and one conclusion is inevitable, viz., that the practice of slow combustion is eminently conducive to economy in the treatment of fuel; nor can there be a doubt that the metal of which a boiler is composed is principally affected, both in its strength and durability, by the heat applied to it, so that these properties seem to be best preserved by, and to be the natural consequences of, slow combustion. Thus we shall find that the boilers, tested as to their merit by their respective evaporative economy, arrange themselves for consideration in the inverse order of the rate of combustion, and that the Cornish boiler, in this respect, obtains the highest rank.

A second though somewhat less regular coincidence between the operating causes and economical results, is indicated by the extent of surface exposed to absorb the heat supplied to the boiler. This element is subject to more or less of modification from a variety of contending circumstances, which will severally be noticed and considered in the ensuing observations on the practice of each class of boiler; but the table shews distinctly that economy of heat is promoted in some proportion of the extent of the absorbing surface, and the Cornish boiler again exhibits its superiority over all the others by the degree in which it possesses this element.

Time—used in the sense before explained, and which expresses the rate of combustion involved with the extent of the absorbing surface—is also greatly in favour of the Cornish boiler.

As that boiler and practice, therefore, afford the highest evaporative product, and appear to combine the greatest number of good qualities, and as it is re-

quisite that a standard should be adopted, in order to mark the scale of descent from the highest point of excellence yet attained in evaporative economy, I shall bring the other boilers to the test of the Cornish, with reference to their respective properties, and consider the Cornish results as unity.

CORNISH BOILER.

EXPONENTS *.

Column of Table.	lbs.	
48....	1	of coal burnt under one boiler in 44.08 seconds.
20....	3.46	of coal burnt on each square foot of grate per hour.
41....	1	of water evaporated by 1 square foot of heated surface per hour from 212°.
37....	11.82	of water evaporated by 1 lb. of coal from 212°.

The form, construction, usual dimensions, and mode of setting this boiler are too well known to require particular mention. It appears to possess all the principles necessary to resist internal and external pressure, due regard being paid to sufficient strength of materials. The fire is contained in an internal cylindrical tube, the pressure upon which being external, the greatest strength of resistance is obtained where it is most needed; nor can there be so great a lodgment of deposit upon the parts subjected to the most direct and intense heat as in the wagon boiler. The practice as regards the slow rate of combustion is eminently judicious, since it involves the necessity of employing a very extensive surface, or proportion of boiler to evaporation, for the absorption of the heat; which again, together with the requisite strength, occasions the use of several boilers of small diameters, rather than few of larger dimensions. By these means *time* is given for the complete combination of air with the heated fuel; *time* is given for the transmission of the heat through the metal; and *time* is given for the escape of the steam through the water. These are points of practice of great import to all boilers and to the well working of every species of steam-engine; but they are of still greater consequence to an engine using steam at a very elevated pressure, and employing that steam expansively. The durability

* The quantities brought from Table I. and thus placed at the head of the observations on each group or class of boilers, are those which form the principal points of contrast and comparison. They are indicative or exponential of the quality of the boiler and of the effects of the practice upon it; I have, therefore, termed them *exponents*.

of a boiler is greatly prolonged by using heat of a moderate intensity. Much thicker plates are indispensable in proportion as the pressures become elevated, and in proportion also to thickness of material, the conduction of heat is slower; hence the wisdom of reducing the combustion of the fuel to the slowest possible rate under all, but more particularly under high pressure boilers; and hence durability and safety are promoted in proportion to the diminution of calorific intensity; yet it would not be difficult to shew that, except by the Cornish engineers, the practice obtains too often of increasing both the extent and intensity of the fires almost in the ratio of the increased pressure of steam, from which practice arises one fertile source of short-lived boilers, and explosions.

It appears from the Table, column 45, that the Cornish engineers allow about 7 times as much surface as the general wagon boiler practice for the vaporization of equal weights of water in equal times, which is accompanied by a gain of between 30 and 40 per cent. on the mean of the 8 wagon boiler experiments, some of which, however, far exceed the average product of those boilers in common practice.

It must be carefully borne in mind that two very remarkable differences exist between the high and low pressure boilers under comparison; viz. the thickness of plates, and the temperature of water and steam within the boilers. The plates of a Cornish boiler are never less than $\frac{1}{2}$ an inch thick, those of a low pressure boiler usually $\frac{1}{4}$ to $\frac{5}{16}$ of an inch. A much larger extent of surface is consequently necessary in order to transmit a given quantity of heat, in a given time, through the thicker than the thinner material without injury; more particularly when the contained water, which abstracts the heat, is at a temperature of not less than 300° in the one, and not more than 220° in the other. The Cornish practice shews an intimate perception and knowledge of the advantages arising from this extent of surface, though I cannot find that the subject has ever been treated of by Cornish authors, which is the more to be regretted as an infinite variety of experiments have been made in Cornwall on the proportions of grates to the combustion; on the arrangement and proportions of the internal and external surfaces exposed to heat; on the mode of setting the boilers, introducing the feed, &c. So habituated also are the operative engineers and firemen to a comparison of the work done by the engine with the fuel consumed, that they are thoroughly versed in their business as an *art*, their skill being subject to strict and constant test by the daily registration

of the *duty* of the engine, the amount of which depends, in no slight degree, on the management of the fires and boilers.

The Cornish surface, to produce equal effects, is 12 times greater than the locomotive, from which a gain of 64 per cent. arises compared with coke, and about 100 per cent. when coal is used by the latter.

Combined with this economy, the *durability* of the Cornish boiler is at least equal to that of the wagon, or other low pressure ones; and its *safety*, though usually subjected to 15 times the pressure, is certainly not inferior, explosions being as infrequent in Cornwall as elsewhere.

As regards *cumbrousness* the Cornish boiler occupies less space than the wagon form for equal surfaces exposed to heat, somewhat more than one half of the entire area acted upon being contained within the exterior shell. From the same cause, joined with the mode of setting, the upper surface of steam-chamber and flue is also less extensive, and consequently the loss arising from radiation is diminished in the same proportion. This loss is reduced still further by the universal practice in Cornwall of covering the boiler with a thick stratum of slowly-conducting matter.

WAGON BOILER.

EXPONENTS.

Warwick Experiments.

Column of Table.	lbs.	
48....	1	of coal burnt under one boiler in 38.31 seconds.
20....	4	of coal burnt on each square foot of grate per hour.
41....	6.39	of water evaporated by 1 square foot of heated surface per hour from 212°.
37....	10.32	of water evaporated by 1 lb. of coal from 212°.

Mean of the eight Experiments.

48....	1	of coal burnt under one boiler in 16.57 seconds.
20....	10.75	of coal burnt per square foot of grate per hour.
41....	$7\frac{1}{10}$	of water evaporated by 1 square foot of heated surface per hour from 212°.
37....	8.86	of water evaporated by 1 lb. of coal from 212°.

But few observations are necessary on this well known vessel. As regards structure it has nothing to recommend it, being inherently weak, and

requiring stays to enable it to resist the small amount of internal pressure to which it is usually subjected. It is very susceptible of injury from collapse, if abundant provision be not made to supply it with air in the event of a vacuum. It is much affected by incrustation from deposit falling on the parts exposed to the greatest heat, causing leakage and frequent repairs, which, with the wear and tear of brickwork, occasion this kind of boiler to be much more costly in its maintenance than the Cornish.

The comparison of the Warwick with the Cornish results shews that in the former,

The rate of combustion is $\frac{1}{7}$th more rapid per boiler, and per square foot of grate per hour.

The rate of evaporation is $6\frac{1}{2}$ times more rapid from equal surfaces.

The loss of heat (the Cornish being unity) $12\frac{3}{4}$ per cent.

The results of the mean of the eight other experiments on the wagon boiler compared with the Cornish, show that in the former,

The rate of combustion is $2\frac{6}{10}$ times more rapid per boiler, and 3 times more rapid per square foot of grate per hour.

The rate of evaporation is 7 times more rapid from equal surfaces.

The loss of heat (the Cornish being unity) $24\frac{1}{2}$ per cent.

In contrasting the Warwick with the Cornish results, there are two corrections to be made before the experiments can be put on equal terms. Firstly, in the Warwick the whole of the smoke was inflamed, the practical evaporative value of which, from the experiments related in my former paper, appears to be about 12 per cent. In the Cornish the smoke passed off unconsumed; the result of the Warwick experiments must consequently be diminished 12 per cent., or the Cornish raised in that amount. This would cause the real difference in favour of the latter to be about 25 per cent. But there is a second correction to be made.

The result of my experiments at Warwick, during six months' continuance, is $18\frac{1}{2}$ cubic feet of water evaporated by 112 lbs. of coal from 212°, all waste and loss in the raking and banking up of the fires at night included. The Cornish, especially those at the United Mines, are also experiments of long continuance, waste and loss included, but as those engines work night and day, there is no loss arising from banking up the fires, or from radiation during the night. A diminution of the weight of coal used at Warwick is therefore required, equal to that burnt during the night and for raising the steam each

day. This amount, from the system of management I pursued, was exceedingly small. When the engine stopped at night, the hot coal upon the grate was pushed back upon a dead hearth formed of brickwork at the end of the grate, but the bars were not left uncovered, nor the grates scaled or cleaned; it being found that the scoriæ and refuse were removed with much less labour to the fireman in the morning when cool. The water having been allowed to sink as low as possible in the boilers before the stopping time, they were then filled from the feed reservoir as high as they would bear, the fires damped down with two or three shovels full of well wetted sleck mixed with finely riddled cinders, and the dampers so closely shut as to preserve only the smallest possible amount of draft. By these precautions no steam blew away during the night—fully three hours' supply of water was brought to the boiling point during the night—and the boilers being well covered, the radiation was trifling, and the fire was no sooner spread upon the grates in the morning, than the steam was up. By these simple means the loss by stopping 11 hours during the night and by getting up the steam again, which commonly amounts to 15 and even 20 per cent. of the entire weight of coal used to work an engine during the day, was reduced to 3 per cent.; by this amount therefore the loss in economy by the Warwick compared with the Cornish experiments must be diminished. Thus the real difference in favour of the Cornish is 22 per cent.

I have been thus particular in bringing these results to a fair comparison, as there is an almost perfect coincidence between the two experiments in the rates of combustion, and in the rates of evaporation by the products of combustion from each square foot of grate per hour, and thus the difference in performance seems to be referable simply to the superiority of one quality in the Cornish boilers, viz., the larger comparative area for the absorption of the heat generated in a given time, which, as appears by column 43, was as 11.7 to 1.6 or $7\frac{3}{10}$ to 1. We must not conclude that it requires 7 times as great a surface exposed to heat *under like circumstances,* to realize an additional product of only 22 per cent. from fuel. I must again advert to an important disagreement between the circumstances of the two experiments, viz., the thickness of material, and the temperature of the water. The Cornish boilers were double the strength of the Warwick, and the water in the former was nearly 100° hotter than in the latter. Ignorant as we are of the rate at which heat is transmissible through metal of varying thickness, and equally so as to the rate in which it is absorbable by water at different temperatures, it is impossible to decide, except by direct experiment, on the relative areas which would produce equal effects, the surfaces

being composed of plates of $\frac{1}{2}$ inch and $\frac{1}{4}$ inch thickness, and transmitting heat respectively to water at 300° and 218°.

Notwithstanding also the near identity of the principal forces which seem to affect the evaporative product, there are differences in these two experiments among the minor causes in operation, which may have had an influence over the results. I allude to the proportions of the surfaces exposed to the radiating action of the fire compared with the weight of coal burnt in a given time, and with the surfaces exposed to what is commonly termed communicative heat. There is a near equality between the coal burnt and the radiant surface in the two experiments, but the difference is somewhat greater between the communicative areas, than between the total amounts of heated surface. Definite experiments are again wanting to determine the respective value of these portions of a boiler; but it will appear from some future remarks on this subject, that their indications are entitled to little confidence as general rules, excepting when the practice is precisely conformable to the particular experiment *.

By comparison with the Warwick, the result of the mean of the eight other experiments on the wagon boiler shews,—

The rate of combustion per boiler to be $2\frac{3}{10}$ times more rapid, and $2\frac{7}{10}$ times more rapid per square foot of grate per hour.

The rate of evaporation from equal surfaces $\frac{1}{8}$th more rapid.

The loss of heat (the Warwick being unity) $12\frac{1}{2}$ per cent.

This loss would amount to at least 25 per cent. on the mean if the VIIth, IXth, Xth, and XIIIth experiments in the Table, which were made on the Warwick system, and fully explained in my former paper, were excluded, and the comparison strictly made with those boilers only whose proportions of grates and method of practice were different. I have already contrasted the rationale of the Warwick and Cornish, as the former occupied an intermediate rank between the latter and the mean of all the others; and as I am not advocating my own or any other particular system, but endeavour merely to ascertain, by a rigid examination of the conditions of a series of experiments entitled to entire confidence, the causes which have produced various and particular effects, (and the experiments would be nothing worth did they not lead to some such useful end,) I have thought that end more likely to be attained by striking a mean from a large number of experiments on the same class of boiler treated on different plans. But no one can cast his eye over the Table without perceiving very marked differences in the ratios of the several parts of the wagon boilers under review,

* See pages 29 and 30.

as also in their evaporative products, which vary as much as 65 per cent. Though, therefore, the more active causes which influence the evaporative economy of steam boilers develop themselves prominently and decidedly by comparing three distinct and widely different systems of generating steam, as indicated by the Cornish, wagon, and locomotive practice, much instruction is derivable from the mutual examination of boilers of the same class, particularly when a change in the effect has been produced by some single change in the conditions of an experiment on the same boiler.

The Table presents several such on the wagon boilers. The VIth and VIIth experiments were made on the same boiler with one change; in the VIIth the grate was enlarged $\frac{1}{5}$th, but the whole capacity of the furnace about $\frac{1}{2}$, fired in each case in the same manner, and doing nearly equal work in the same time. The result was an economy of 50 per cent.

The effect of this simple alteration is clearly traceable through all the columns. The rate of combustion per square foot of grate fell from $11\frac{1}{2}$ lbs. to 8 lbs. per hour, and the proportion of surface to absorb the heat was consequently greater: in fact, the combustion was more perfect, and more time was given to transmit its product. The evaporative power of the boiler was also increased by the same causes.

Experiments VIII. and IX., at another place, with a boiler of very different proportions, furnish instructive facts. No alteration was made in the grate of this boiler, as it then appeared to me of a good proportion, though I should now somewhat enlarge it. The difference between the two experiments amounting to about 14 per cent., was simply caused by the more perfect combustion of the fuel in the IXth from a thickened mass of fire and the more perfect inflammation of its gaseous products, accompanied by a diminished rate of combustion, and a somewhat increased evaporative power as well as economy.

As this boiler was attached to a chimney of remarkable draft, I determined on making an experiment to ascertain the utmost amount of evaporation producible from the boiler. Every thing remaining the same, Experiment X. was undertaken, and to guard against any loss of heat by opening the fire doors during the process, the water was first brought up to the boiling point, the few hot coals on the grate were raked into a small heap on its centre, and the raw coal, amounting to about 2400 lbs., was then shovelled as quickly as possible into the furnace, until it was crammed quite full; the fire doors were then hermetically closed by filling the mouth-piece with well wetted

sleck. The damper for the first hour was kept almost close down, and when the regular rate of evaporation exhibited itself, which indicated—together with the vivid and uniform reflexion of the fire in the ash-pit—that the bars were well covered with ignited coal, the damper was very gradually raised, till the whole force of the draft was given to the furnace. The evaporation then became excessively rapid, and at the end of the fifth hour the fire was examined, that no aperture might be left for uncombined air to pass through it. The remainder of the coal was then thrown on, amounting to about 238 lbs., and the experiment continued till the whole was consumed, the damper being again gradually lowered as the thickness of fuel diminished.

One result rather surprised me, which was, that notwithstanding the rapidity of the current, and the certainty that the heat must have quitted the boiler in much greater quantity, and at a much higher temperature than in the IXth experiment, a very slight difference appeared in the weight of water evaporated by each pound of coal. The experimenters judged that two-thirds of the coal burnt and of water evaporated was accomplished in one half of the whole time, or in four hours; which would be, as regards combustion, at the rate of 15 lbs. per square foot of grate per hour. The ordinary working rate of that boiler was about 9 lbs., and from the appearance of intenseness in the fire and other indications, it was clearly perceptible that the rate of 15 lbs. per hour per square foot of grate was far too rapid a combustion for any boiler to sustain long without injury, particularly if supplied with water of bad quality. A practised eye is not a bad pyrometer, and without the aid of the latter instrument it was no presumption to conclude that such intensity of heat must speedily affect both the safety and durability of the vessel.

The almost inappreciable difference in the economic results of these last two experiments might seem to favour the opinion that very rapid combustion is not unfavourable to economy. It is, however, necessary to keep in mind that the experiment was conducted with precautions which cannot be carried into practice. An experiment of short duration was afterwards tried on the same boiler by attempting to burn about three hundred weight of coal per hour, or the same rate of 15 lbs. per square foot of grate per hour, with an even and regular fire; but it was accomplished with difficulty, with great waste from being obliged to widen the air spaces between the bars, and with great loss in evaporative product.

Another practical evil must ever accompany rapid combustion. The cleanest and dearest coals are necessary, or increased waste arises from the necessity of frequent poking and clearing the grate. That system of management which discards altogether, or renders the use of the poker but little necessary, will always be attended with the most productive results*.

The XIth experiment is Watt's, at the Albion Mills, the particulars of which, as also the XIVth, of Smeaton's, will be found recorded with useful minuteness of detail in Volume I. of Mr. Farey's work on the Steam Engine.

The boiler fixed by Watt at that engine differs from his later practice in proportion of parts, though there is a near parity in the total area of heated surface, which he subsequently adopted for the vaporization of a given weight of water in a certain time. The change was judicious, as it will be seen that the combustion was effected at a rate nearly of $16\frac{1}{2}$ lbs. of coal per square foot of grate per hour at the Albion Mills; whilst at the New River Water Works, experiment XIII., also Watt's boilers, the combustion took place at $12\frac{3}{4}$ lbs,; upon which latter it will be seen, by experiment XIV., that a gain of $16\frac{1}{2}$ per cent. in evaporative economy was effected, chiefly by an enlargement

* After many trials I succeeded for a week in working my own boilers with fires made up on the previous night, so that no fire door was opened during the day till late in the afternoon, in order to examine and level the unconsumed fuel. The evaporation told the advantage of this process by rising from $18\frac{1}{2}$ to 19 cubic feet per 112 lbs. of coal. It required, however, somewhat more dexterity and judgment in its management than could be often met with in a fireman in order to carry this plan into regular practice. It was necessary that the furnaces should cool down below the temperature at which the coal and its gases would ignite, before the operation of charging could be safely commenced; and it required much judgment in determining both the quantity and position on the grate of the hot coal which was to remain during the night—with as little activity as possible—in the midst of the charge, as a nucleus for the morning's fires.

By this experiment, however, I ascertained that which I desired to know, viz., the loss occasioned by the opening of the fire doors during the process of charging on my regular system. This loss, strictly speaking, should not be spread over the whole day's work, but be reckoned on that portion of it only which was performed in the first three hours; nor am I disposed to assign the advantage, which would thus appear considerable, to the above cause solely. The experiment shewed me that the greater part of the scoriæ was formed during the time of charging, when the dampers were necessarily wide open and the draft rapid, as clinker vanished altogether during these experiments, in consequence of the temperature of the fires being, from the beginning to the end, in the same equable state, and at no time intense enough to fuse the impurities. By keeping below this point the poker was needless, and every atom of coal was burnt up completely and usefully.

of the grates, which reduced the rate of combustion to about $6\frac{1}{4}$ lbs. per square foot of grate per hour. The Albion Mills' boiler, notwithstanding the swift combustion of the fuel, evaporated nearly as much water as the best of the other wagon boilers in the Table, the Warwick excepted. I consider this isolated exception to the results indicated by all the other experiments as regards the effect of the rate of combustion, to have been modified by the peculiar structure of the boiler; viz., by its presenting, as shewn in column 11, a much larger surface of internal flue, in proportion to that of the whole boiler, which compensated, by its superior efficiency in the transmission of heat to the water over an equal area of side flue, for the loss which could not but have resulted, had the same area consisted only of external surface. In this respect that boiler approximated more nearly than any of the other wagon boilers to one of the best properties of the Cornish construction, more than the half of whose heated surface is entirely surrounded by water; and it will be seen that its product considerably exceeded that of the London boilers, which had no internal flue, and nearly equalled the performance of the Clithero and Preston boilers which had internal flues, and whose rates of evaporation from equal areas were nearly identical with that at the Albion Mills. In like manner, the absence of internal flue in the London boilers seems to account in some degree for their inferior performance as compared with the Clithero and Preston experiments. Though, therefore, in assigning to boilers a certain power of generating steam from some certain area exposed to heat, it is necessary to discriminate between the vaporizing value of the arrangement of the surfaces; of which at present we may be called entirely ignorant.

The absence of internal flues in the Warwick boilers was compensated, or much modified, by the peculiar treatment of the fuel, and the diminished rate of combustion previously described; but there can be no doubt, by the comparison of parts and results with the Cornish, that the evaporation would have been effected with still less fuel from the former, had those boilers been supplied with internal flues.

These indications of the greater efficiency of interior over exterior surfaces, point to the probability that equal areas of the marine boiler would exceed, in evaporative value, equal areas of the boilers under review, provided the element *time*, and *intensity of calorific action*, as hereafter to be explained, be judiciously incorporated with the practice. A knowledge of the evaporative economy and power of the marine boiler would greatly tend to enlighten us

on the respective value of surfaces exposed to heat within and without the water.

All the foregoing conclusions are liable to a certain amount of error from the want of identity in the coals employed in the different experiments, not as regards the chief elements affecting evaporative economy, but as respects the mutual comparison of results from boilers of the same class. There is, however, a curious fact yet to be pointed out, which will shew these observations and deductions to be free from any gross error occasioned by the use of a variety of coals in the different experiments.

By comparing experiments VI., VIII., and XII., which were conducted according to the usual practice at the three establishments with all possible care and skill on the common plan of firing, and with three varieties of coal, it appears that there was a difference of 13 per cent. between the greatest and least result, which would have been attributed to the varying strength of the coals; but when these same coals were treated under the same boilers, as in experiments VII., IX., and XIII. by a different manner, viz., by a slower rate of combustion, &c., the gross difference is only 7 per cent., and the product between two out of the three experiments is identical. The attentive mind will also see good reason to conclude, by inspecting the peculiar properties of the boilers experimented upon, that even this slight difference of 7 per cent. is attributable to other causes rather than to the fuel*. A true estimate of the practical value of varieties of coal can, therefore, only be formed by treating them in such a way as to cause the development of their full force; and the cheaper coals—cheaper, generally, because less fitted for house fires and delicate purposes—do often, in reality, contain the greatest strength of combustible matter, though mixed with impurities. I tried at Warwick the Newcastle, (Wylam Moor,) the Wednesbury, and the Netherton coals, which gave me, within a fraction, the same result; though Watt and other experimenters assign very varying strengths to them, and the last were the cheapest in price by one half over the Wednesbury, for engine purposes. On the other hand, it not unfrequently happens that a small difference in price is more than compensated by an increased effect from dearer coal. Nor will the same system of treatment invariably succeed. I have been occasionally defeated in every attempt to burn certain sorts of coal on my plan of thick fires, on extensive grates with slow combustion. In one instance, in Lancashire, the coal contained so much tar

* The difference or loss of 7 per cent. is found in that boiler which had no internal flue.

as to run in streams through the bars, and catch fire in the ash-pit; and in Glasgow certain coals defied the system altogether; these were rare instances, but ought to be cited.

If the statement of the fuel burnt and water evaporated by Smeaton's boilers, Experiment XIV., be correctly given by Mr. Farey, the product was not only very good for the period, but is larger than is usually obtained from an equal extent of surface at the present day. The combustion was very rapid, its rate being $20\frac{1}{3}$ lbs. per hour per square foot of grate. The evaporation 8.37 lbs. from 212° by one pound of coal. The dimension of surface exposed to radiant heat not being given, I have assigned to it in the Table the half of the bottom of these circular or *hay-stack* boilers, (as they are commonly termed in Staffordshire, where they are still much used,) having found the practice to be such generally, the bridge wall being built across the centre of the boiler, sloped down to the grate at the sides and ends of the bars. The circular is a good form of boiler for strength; equally bad with the wagon as regards incrustation; but perhaps better adapted for outdoor fixing, as it admits of being more advantageously covered, without a roof, to throw off the rain from the top and walls; but the wagon boiler has so many advantages over it for house fixing, besides admitting of internal flues, and other desiderata, that the use of the circular has long since yielded to the wagon form in the best appointed establishments.

Thus Smeaton's evaporative practice in 1772 appears, from the account extracted from Mr. Farey's work, (which I cannot, however, find in the fourth edition of Smeaton's Reports, 1812, referred to by the latter,) to be, as respects the Cornish of the present day, as 8.37 to 11.82, shewing a gain, since that period, of $41\frac{1}{4}$ per cent. only; an important economy certainly, but miserably small when compared with the strides made in the economy of steam.

Are we then to conclude that our methods of generating heat and steam, and of constructing evaporative vessels, have attained the utmost perfection which the strict laws of nature, and the limited ingenuity of man, forbid us from passing? Or, are we to hope that our knowledge of the theory of combustion, of the most profitable modes of treating combustible bodies, and of applying the heat elicited from them to the vaporization of water, are alike imperfect and alike susceptible of improvement? My own opinion inclines to the more cheering view of the subject, perceiving as I do many sources of waste which may be turned to profit, and believing that combustion, as a science and practical art, has not yet

received that attention which it merits, and whence any very marked augmentation of calorific economy must originate. Numberless as have been the variations in the structure and dimensions of steam-boilers, it appears that the efforts of improvers have been confined within the range of a very small circle; changes have been rung on the same or similar contrivances, but nothing has emerged which at present authorizes any wide departure in practice from long established forms, or which can be characterized as bearing the stamp of inventive genius. Experience, nevertheless, informs us that great diversity exists in the economy of our present practice; the comparative investigation of numerous examples should, therefore, throw a strong light on those principles which are most influential over the results, and it should indicate, with a near approach to certainty, that practice which is most likely to assimilate the product from one boiler with the product from another.

As boilers of the Cornish and wagon forms are by far the most numerous in use, it may be here most convenient, and before entering on the examination of the *locomotive,* to allude to those questions which the intelligent employer of a boiler frequently propounds, and desires to solve, viz. the best proportion of parts, and the best practice. These problems he can now readily solve for himself, by an attentive study of the facts placed before him in the Table.

Does he wish to fix a new boiler? The Cornish points itself out as the best known; and having decided on the quantity of steam he requires in a given time, either for an engine or other purpose, he is furnished with a means of determining the weight of fuel which will generate it, *by rigidly adopting the measures of surface and proportions of parts which have given relative effects.*

Does he desire to ascertain if his present practice be good or defective? As regards the rate of combustion, the simple determination of the weight of coal he is consuming per hour, divided by the area of his grate, will decide that question; and by comparing that product with the entire surface presented to absorb it, he will, if his boiler be well set, arrive at an approximation to the amount of water evaporated on consulting the Table; but no absolute and sufficient knowledge of the economy of his practice is attainable without ascertaining the weight of water vaporized. No one can tell him this fact: *it is the work which his boiler* is doing, and it can only be determined by experiment.

Does he find, after this trial of the evaporation, that an equal surface has produced, from other boilers of the same form, a greater result? He must compare the area of his grate, and the rate of combustion of the fuel with the best parallel examples in the Table, and bring his practice to a conformity with

them if they disagree; this will inform him of the comparative calorific value of the fuel he is using: if he still finds that he is deficient in boiler-power, the only cure is to add more. If circumstances prevent him from so doing, increase of effect and of economy will generally follow the enlargement of a grate to such dimensions as a fireman can skilfully command, the width of which is only limited by that of the boiler, and the length not much exceeding six feet*. There is evidently a considerable range permissible in the rate of combustion, without much loss of effect, or much evil arising to the boiler; but it is also evident that the slowest rate is the best on every account, and that is the point to be aimed at achieving. The combustion should not exceed 7 lbs. per square foot of grate per hour; but it will be the true interest both of the engineer and employer so to proportion parts and practice as to bring the rate of combustion at least as low as 4 lbs. per square foot of grate per hour; and the Table shows that the greatest effect was produced when the boilers were so proportioned as to bring down the combustion to less than 3 lbs. per square foot of grate per hour.

With respect to the setting of a boiler, every respectable engine maker is acquainted with the best methods; and from such persons, or from good examples, the employer of a boiler should take his plans, and not permit so important an element in the final economy of his practice to be left to the discretion of a bricklayer, as is too frequently the case.

But little information, either of scientific or practical value, on the important

* To determine this point satisfactorily to myself, I used, in my early experiments, a *moveable bridge*, commencing with a grate 10 feet in length. The evaporation was noted each day, without which I considered every experiment as valueless. This bridge was traversed a foot at a time nearer to the fire door. The best effect was produced with bars 5 feet 6 inches to 6 feet long, under the Warwick boilers, as per Table I. I found thickness of fuel far more economical than an *excessive* extent of grate surface. No fireman can spread fuel accurately beyond 8 feet from the fire door, which is about the extreme length of a 6 foot grate, including the dead-plate of the furnace mouth. I also found, that beyond 7 feet of bar a sufficient supply of air did not reach the end; that the fuel burnt dull and uselessly; and no doubt much of the air which did enter, passed through the half ignited coals, not only unproductively as an element of combustion, but wastefully, by mixing with and cooling the stream of heat.

With a rate of combustion as slow as 4 lbs. per square foot of grate per hour, a grate (were it practicable) should resemble a fine sieve. My bars, *for this rate of combustion*, were fixed, after numerous trials, at $1\frac{1}{2}$ inch broad on the upper face, and the air spaces between the bars at $\frac{1}{4}$ of an inch wide; consequently, no *cinders* fell through into the ash-pit, the refuse being *ashes*, and utterly worthless. My fireman usually sat in the ash-pit to take his meals, and though he had half a ton of coals on fire above his head, he feared no fall of hot coal, as the poker was never used, nor was the fire door opened but once, after charging, during the entire day.

subjects of steam-generators, combustion, and evaporation, is to be obtained from the numerous works and treatises on the steam-engine. Mr. Farey's volume is chiefly a history of the early inventions and practice; it contains numerous and minute details, and is useful as a record of dimensions and strength of parts. It is to be regretted that the writings of many popular authors abound too much in formulæ and hypotheses, too little in facts: for, unfortunately, the detection of fallacies in particular statements tends to diminish confidence in their general accuracy. It is, however, necessary for the sake of truth—the basis of science—that errors which have crept into works of the highest estimation should be pointed out. Of these several are to be found, as regards the subjects under consideration, in the splendid edition of Tredgold, by Woolhouse, which may be traced (and the same remarks apply with equal force to other authors) to a limited knowledge of ascertained facts on the large scale of practice; to an undue reliance on experiments conducted in the laboratory, or of short duration; to conclusions drawn from the practice of some one engineer, or deduced from the results of some particular class of boiler.

At page 112, a Table is given by Tredgold of the calorific powers of a great variety of combustible substances; and we are told, that 8.22 lbs. of "caking coal" and 9 lbs. of "coke prepared in close vessels," are requisite to convert a cubic foot of water into steam. "These quantities," says the author, (page 113,) "derived entirely from theoretical considerations, are so near to the actual effects obtained in practice, that they shew us we have little to expect in the form of improvement," &c.

Fortunately, the Cornish and other engineers, being more habituated to practical than to "*theoretical considerations*," have thought otherwise, and we happily know that this theoretical barrier has been passed by nearly fifty per cent.; and there is abundant reason for hope that no barrier exists against obtaining still higher results.

He again tells us, page 116, that "one foot area of grate, for each horse power, is the common rule of practical engineers." I can find no such agreement in the practice of engine makers, which is as various as their number is large; the practicable size of a grate depends very much on the width of the boiler, and the widths of boilers on the fancy of their makers.

A rule is also given, pages 115 and 116, for the width of air space between the grate bars, and much learning is exhibited in determining the coincidence of results, as flowing from hypothesis and formulæ, with the presumed practice. We are informed, that one-third the width of the fire-bar is a good

rule for the air space, without any reference to the rate of combustion, or to the peculiar nature of the fuel, and without perceiving, that upon the width of the air space materially depends the waste in the ash-pit, and other important consequences; and the rule leads to this absurdity, that a fire-bar three inches broad must have an inch air space; and one of an inch in width, an air space of one-third of an inch, and so on.

We are also informed, page 118, that for low-pressure boilers, the best effect from fuel will be obtained by 8.1 square feet to vaporize one cubic foot of water per hour, and 8.9 square feet for high-pressure boilers. The most experienced engineers in Lancashire (the practice of which county I quote, as I am better acquainted with it than that of any other part of England) allow at least from 12 to 15 square feet for low pressure, and the Cornish engineers from 60 to 70 square feet for high-pressure purposes, in order to obtain that effect as shewn in Table I., columns 46 and 47.

Smeaton's experiments on coal of several varieties, coke, wood, &c., are repeatedly cited, and pass from treatise to treatise as decisive, or at least illustrative of the respective calorific value of these combustibles. Smeaton's experiments were made on a boiler only $2\frac{1}{2}$ feet in diameter, and it requires no reasoning to shew that the grate and the setting which would suit one combustible, would be utterly unfitted to develope the powers of another; and that experiments, conducted on so diminutive a boiler, can give at best but deceptive indications of the effects of combustibles on the large scale of practice.

The name, experiments, and practice of Watt are also very commonly used by writers on the Steam Engine as arguments and data for empirical rules which Watt would have been the first to repudiate. This is a system which cannot be too strongly reprobated; it has had the effect of restricting rather than of extending the conquests and realm of science; and much injustice has been done to the character of these distinguished men by the excessive zeal of disciples. Smeaton and Watt were not merely engineers; they were great *practical philosophers;* their career was marked by a succession of bounds over mechanical obstacles; their writings exhibit a modesty becoming greatness; and in giving to the world an account of their experiments and discoveries, they never dreamed that they would be regarded as laws to control future ages, or be viewed otherwise than as progressive steps towards the attainment of a perfection in their favourite pursuits, which they well knew neither the life nor the labours of any single man (however great his genius) could accomplish.

LOCOMOTIVE BOILER.

EXPONENTS.

Column of Table.	lbs.	
48....	1	of coke burnt under one boiler in 6.45 seconds.
20....	79.33	of coke burnt on each square foot of grate per hour.
41....	12	of water evaporated by one square foot of heated surface per hour from 212°.
37....	7.21	of water evaporated by 1 lb. of *coke*, from 212°.
Calculated....	5.77	of water evaporated by 1 lb. of *coal* from 212°.
Mr. Wood....	5.17	of water evaporated by 1 lb. of *coal* from 212°.

The circumstances under which locomotive boilers are worked,—their dimensions, construction, strength, and nature of materials, are so widely dissimilar to every other species of evaporative vessel, that it would be vain to attempt to draw any other conclusion as to their merits than that which is furnished by their practical results. Strict analogy between them and others ceases with the production of heat, for such is the devouring nature of the locomotive engine, so short the time allowed for the heat to act on the surface of boiler exposed to it, and so limited the space assigned for generating steam, that the processes by which economy is sought at fixed engines would seem to be thought unattainable in the locomotive, and recourse is had to other contrivances. The generation of heat and steam in the locomotive is, however, governed by precisely the same laws as in other boilers, and the economical inferiority of that boiler must be owing either to the absence of some one or more of those elements which comparison shews chiefly to influence their economic results; or to the presence of some bad quality, from which other boilers are exempt. The decomposition of its parts and effects exhibited in the Table, enables us to ascertain in what respects the locomotive boiler and practice differ from that of the Cornish and wagon boilers, and to assign, with tolerable certainty, the true causes for their widely different evaporative economy. The comparison of Experiment XVI., (which is the mean of eleven experiments made by M. de Pambour on six engines on the Liverpool and Manchester Railway in 1834,) with the mean of the Cornish is, that

The rate of combustion per boiler is $6\frac{8}{10}$ times more rapid.

The rate of combustion per square foot of grate per hour, 23 times more rapid.

The rate of evaporation from equal surfaces, 12 times more rapid.

The loss of heat, (the Cornish being unity,) 51 per cent.

The comparison of the locomotive with the mean of the eight experiments on the wagon boilers, shews, that

The rate of combustion per boiler is $2\frac{1}{2}$ times more rapid.

The rate of combustion per square foot of grate per hour, is 7 times as rapid.

The rate of evaporation from equal surfaces, $\frac{7}{10}$ths more rapid.

The loss of heat, (the mean wagon being unity,) 27 per cent.

It would be mere waste of words to institute any more minute comparison between the locomotive and the Cornish boilers, than is given above.

It may not, however, be uninteresting, nor altogether useless, to shew how entirely the relation between boilers of equal surfaces is disturbed by a different practice as regards rapidity of combustion, and by a different arrangement and strength of parts and metal. The comparison between the locomotive and the mean of the eight wagon boiler experiments, is, for this purpose, as perfect as if a single boiler of each class had been constructed with the express intention of submitting the two vessels to the most rigid tests. By referring to the Table, it will be seen, that there is an almost perfect identity in the total, in the radiant, and in the communicative areas, between the mean of the eight experiments on the wagon, and that of the eleven experiments on the locomotive boiler. So perfect an analogy between the boilers, resulting too from such numerous experiments, renders the accuracy of the conclusions deducible from an analysis of the respective practice, unassailable by the most fastidious experimenter.

We observe, then, first, that a near equality exists in the entire surfaces exposed to absorb the heat—also, between the respective areas receiving the radiant and communicative caloric; but, comparing the relation between the areas of the grates, that of the wagon-boiler exceeds the locomotive in the ratio of $3\frac{7}{10}$ to 1; the same difference, therefore, obtains inversely between the ratios of the areas of the grates to the total surfaces. The locomotive boiler would thus necessarily have the advantage of presenting between three and four times greater surface to absorb the heat generated on the grate, if the rate of combustion, or the weight of fuel burnt on each square foot of grate in equal times, were alike in the two experiments. But this is not the case; double the weight of fuel is burnt on the grate of the locomotive, in the same time, as on that of the wagon boiler, which is $3\frac{7}{10}$ times larger, and the consequence is, that the rate of combustion in the locomotive is seven times more rapid, and that it offers only $\frac{4}{9}$ths the surface of the wagon boiler for the absorption of equal quantities of heat in equal times—or, in more accurate language, for the absorption of the *heat produced from equal weights of fuel in the same time.*

The equality, therefore, which seemingly exists between the two boilers is merely an equality of figures.

The result of this discordant practice on the two boilers is, as before shewn, a loss by the locomotive of $\frac{1}{3}$rd the value of that proportion of the entire heat of the fuel which has been realized by the wagon boiler. The rate of evaporation from equal surfaces is augmented in the locomotive by 65 per cent.; so that the attempt to increase what is termed *evaporative power*, by that amount, has been attended by a sacrifice of 33 per cent. of fuel. As regards the Cornish, we have also seen, that the attempt to increase the rate of evaporation 12 times, is accompanied by a loss in evaporative economy of 51 per cent.

The nature and strength of the locomotive surfaces form a striking contrast with the corresponding parts of the wagon boiler, and had not some antagonist quality of an overwhelming character influenced the result, the locomotive ought to have exhibited a performance greatly superior to that of the wagon boiler.

The radiant is to the communicative area of the locomotive as 1 to 7; in other words, the surface exposed to the direct action of the fire is $\frac{1}{8}$th, and that of the remainder $\frac{7}{8}$ths of the whole boiler, in which there is a near correspondence between it and the wagon boiler. The metal of the locomotive radiant surface may be called nearly twice as thick as that of the wagon boiler, which is unfavourable—but the communicative area being composed of tubes not exceeding one quarter or one third the thickness of the wagon boiler, infinitely more than restores the balance in favour of the locomotive; and though, as before observed, we have no definite knowledge of the heat-transmitting powers of metal of varying thicknesses, we do know that the times of transmission are greatly accelerated by employing thin substances, and the conclusion will not be disputed that if $\frac{7}{8}$ths of the surface of the wagon boiler were put upon equal terms with the locomotive by diminishing its thickness $\frac{2}{3}$ds or $\frac{3}{4}$ths, a very much larger portion of the entire heat would have been absorbed, and the economical result have been considerably augmented in the wagon boiler: and, conversely, we know that if the tubes of the locomotive consisted of metal three or four times as thick, the product in steam from equal amounts of heat, would have been very considerably diminished.

Another marked advantage in favour of the locomotive, arises from the distribution of the heat, through the subdivision of its volume among such numer-

ous thin tubes. This principle of breaking up the heat into fragments is evidently one of exceeding great consequence in the construction of boilers whose purpose requires that their dimensions and weight should be compressed into the smallest possible bulk.

The antagonist quality, which has exerted an influence over the result so powerful as not only to neutralize these superior properties of the locomotive, but to reduce their effect so far below that of the boiler compared with it, seems to be solely referable to the operation of the element *time*. The mean length traversed by the heat in the locomotives under review, was 7 feet, whilst that of the mean of the wagon boilers was $72\frac{1}{2}$ feet, or a difference nearly of 10 to 1. The combustion of the first was at the rate of 9.3 lbs. of coke, and of the second at the rate of 3.6 lbs. of coal per minute. In a minute of time, therefore, the whole volume of the heat generated from 9.3 lbs. of coke, quitted the boiler after travelling only 7 feet, whilst the heat of 3.6 lbs. of coal did not escape till it had travelled $72\frac{1}{2}$ feet; in other words, every particle or atom of heat remained $26\frac{1}{2}$ times longer in operation on the surface of the wagon, than on that of the locomotive boiler.

Thus, on the score of economy of heat, the present disposition of the parts of a locomotive boiler is evidently unequal to contend with this powerful adversary; and certain it is that neither the quality, economy, nor durability can ever be engrafted on boilers of the present construction and proportion of parts, with the existing practice; and it is equally certain that no mere change of form or proportion of parts would effect an improvement of much consequence until the element *time* be permitted, in some shape or other, to enter into locomotive practice as a reasonable ingredient in the generation of heat and steam. The locomotive boiler is a striking instance of what consummate constructive skill can effect in endeavouring to pass a boundary opposed alike by the constitution of metals, and by the warning results of all previous experience. Every sound principle is sacrificed to the rapid production of steam; steam is bought at the price of gold; and the absence of the quality durability, involves expenses unknown in other engines, from the practice of connecting almost every part of the engine with the boiler. If this intimate union of the boiler with the engine be unavoidable, or indispensable, the durability of the former ought to be a quality especially sought after. Economy in the production of steam, and durability of the vessel, are nearly synonymous terms; both qualities being obtained by a judicious disposition of parts, and by a judicious practice and manage-

ment. The safety of the vessel as regards explosions is also a property nearly allied to the two others, so far as the metal is affected by the heat. The locomotive is free from one bad quality, possessed in excess by wagon boilers, the precipitates from the water do not fall upon the parts exposed to the greatest heat. The tubes also seem to be weaker than the external cylinder which contains them, and generally also than the fire box, so that though these are continually bursting, no great harm ensues; nevertheless, the absence of many very violent explosions seems to be fairly attributable rather to the constant presence of the engine-man, and to the inadequacy of the boiler to its work when leakages denote weakness and the necessity of repair, than to any inherent principles of safety in the vessel itself. The rapid decay of the fire box and tubes of the locomotive boiler—uninfluenced as that decay is by the incrustation of deposit—affords us a definite and valuable fact, free from any disturbing considerations, which incontestably proves that heat may be supplied to a vessel containing water at such an intensity and in such quantity that its transmission cannot be effected, without speedily destroying the virtue of the metal; and the short-lived existence of these boilers in a sound and healthy condition proves that the temperature of the fire far exceeds the limit at which it can be applied with impunity. The metal of a condemned fire box frequently appears on examination to have lost all its original characteristics; there are no remains of fibrous or crystalline appearance; both copper and iron seem to be transmuted into a species of metallic cake, brittle, of no lustre, and yielding to the slightest blow.

For the sake of simplifying the Table, I have given only the mean of M. de Pambour's eleven experiments, but persons interested in locomotive boilers will not find their labour lost by reducing each experiment to the terms of the Table and submitting them to mutual examination. This will be rendered more apparent from the following notice of a very useful experiment by Mr. Robert Stephenson, which I feel impelled to make, as that experiment appears to me to have been greatly strained in its application by writers on railways.

With the view of obtaining a theoretic expression for the unit of heating surface, necessary to effect the requisite evaporation for the supply of a locomotive engine, M. de Pambour has used the experiment referred to, as detailed by Mr. Wood in his Treatise on Railways*, from which it would appear that

* Wood on Railways, 1st ed. page 403, and 3d ed. page 528.

the effects of the surfaces exposed to the radiant and communicative heat, stand to each other in the ratio of three to one. "If we admit (says M. de Pambour, page 179,) in consequence of the experiment related in our first chapter, that each unit of surface exposed to the communicative heat, produces a third part of the effect that same surface would produce if exposed to the radiating caloric, the heating surface above (viz., 41.47 square feet fire box, and 293.11 square feet tubes) may be represented by 139.24 square feet exposed to the immediate or radiating action of the fire ; and as those 139.24 square feet have produced in an hour the evaporation of 55.32 cubic feet, we see that each square foot has evaporated a volume of water expressed by 0.401 cubic feet."

The conclusion here drawn is, however, inadmissible, and inconsistent with the facts clearly shewn by the mutual comparison of the surfaces of fire boxes and tubes with the evaporation, in five out of the six engines which formed the subjects of M. de Pambour's own experiments. 1st. The Atlas's boiler has a fire box of 57, and the Vesta's one of 46 square feet, difference 11 square feet, which multiplied by 3 gives 33 square feet assumed to be its equivalent in tubes. This sum added to 218, the area of the Atlas's tubes, makes 251 square feet, which is the area of the Vesta's tubes within five feet; yet the Vesta with the smaller fire box exceeded the Atlas in evaporative economy by 11 per cent.! 2dly. The Vesta's fire box exceeds the Vulcan's by $11\frac{1}{2}$ square feet, which $\times$ 3, and added to the tubes, makes a total of 290 square feet, and brings the two boilers on the presumed equality as to surfaces within 10 feet; yet the Vulcan with a fire box less than the Vesta's by 25 per cent., exceeded the Vesta in evaporative economy, by 24 per cent.! 3dly. In like manner, the Vulcan, whose fire box was less than that of the Atlas by 39 per cent., exceeded the latter in economy by 46 per cent.! 4thly. The Leeds, of precisely the same proportions as the Vulcan, gave similar results! And 5thly. The Fury, whose fire box was somewhat less than that of the Leeds and Vulcan, having tubes coinciding in surface with them, also greatly exceeds both the Atlas and Vesta, though it is a little, and but little, inferior to the Vulcan! The Firefly I exclude from comparison, (though it proves the same fact,) as that engine and boiler were not thought to be in very perfect order.

Were the deduction as to the relative evaporative value of the two surfaces correct, the present complex boiler may be discarded, and a simple fire box having a superficies of 140 square feet might be substituted with the certainty of producing equal effects. It does not, however, I think, require the spirit of

prophecy to say that such an arrangement of parts would altogether fail in vaporizing the required weight of water. To effect it from the reduced surface the grate would require to be doubled or trebled in size; and from what has been noticed of the loss traceable to the short distance travelled by the heat, and its short duration about the boiler, it must be quite evident that an arrangement of parts founded on the conclusion drawn by these writers from Mr. Stephenson's experiment, would end in the defeat of their expectations and be accompanied by an enormous waste of fuel. Mr. Stephenson, in stating his experiment originally, seems to have been perfectly aware of its limited nature, and to have cautiously refrained from theorising beyond the facts disclosed by it.—That experiment is instructive so far as it goes, and like effects would have resulted from like surfaces, under similar conditions; but the conditions of the boiler under examination, compared with that operated upon by Mr. Stephenson, are very dissimilar, and have undergone several changes, any one of which would have destroyed identity between the boilers, had such identity even originally existed. The relative areas of the fire boxes and tubes were very different, the ratio between those parts being as 4 to 1 in Mr. Stephenson's, and 7 to 1 in M. de Pambour's boilers. Neither was the experiment made with a blast into the chimney, and there is every reason to conclude that with a greatly increased rate of combustion, which the blast would occasion, a very different proportionate vaporization would have taken place in the fire box and tube compartment of the experimental boiler; and a still greater difference in the respective products of the two compartments would arise from a variation in the area of grate as compared with the two surfaces. The theoretic expression for unit of surface would have been perfectly exact and equally sufficient for M. de Pambour's purpose, by stating that a volume of water expressed by 0.165 cubic feet was evaporated per hour by 1 square foot of surface, which surface consisted of $\frac{1}{8}$th exposed to radiating and $\frac{7}{8}$ths to communicative heat.

We thus see how hazardous it is to quit a fact, for the sake of a neat expression.

The results which I have just stated, as flowing from a strict comparison of the respective surfaces, with the respective evaporative economy, of 5 out of the 6 engines operated upon by M. de Pambour, were to be expected, and might have been foretold; as a larger proportionate area to absorb the heat generated in and escaping from the fire-boxes, allots to each particle of heated matter an increased time to dispose of its caloric; and this conformity with a law which would seem self-evident, and which is seen to pervade

all the other experiments, is satisfactory as tending to confirm our reliance on the care and accuracy bestowed by M. de Pambour on the conduct of his highly valuable experiments; nor would this able experimenter and analyst have fallen into an error of reasoning confuted by his own results, had his attention been equally given to the phenomena of heat, instead of being confined to facts which regarded the engine alone.

Dependent on the proportions of fire box to tubes in the locomotive boiler, other important consequences require notice. The intensity of the heat will be greater in those boilers which present the smallest area to receive the radiating caloric from each pound of coal in an unit of time, than in those exposing a larger area; thus, it seems difficult to combine in the locomotive the greatest sum of economy, with the greatest sum of durability—the dimensions of the boiler being a limited, and the required product of steam a fixed quantity.

In locomotive boilers of equal lengths, and having an equal number of tubes, a larger fire box and grate are necessarily accompanied by a diminished length of tubes; from which change of dimensions four results flow: 1st, a larger area of grate in proportion to the whole amount of fuel burnt upon it; 2ndly, a larger area of radiant surface to absorb the heat of each pound of fuel; 3rdly, a smaller proportionate area to absorb the communicative heat from equal weights of fuel burnt; 4thly, a shorter distance travelled by the heat, and a shorter duration of it in the tube compartment.—It has been shewn that, in economy of fuel, the five engines ranked as follows: Leeds, Vulcan, Fury, Vesta, Atlas; being in the inverse order of the areas of their fire boxes; the fuel consumed per *square foot of fire box per hour*, being in the same order, (with one exception,) viz. 16.03 lbs., 17.11 lbs., 15.31 lbs., 13.55 lbs., 10.58 lbs., a result greatly favouring the durability of the larger fire boxes, whilst the loss in evaporative economy is as clearly traceable to an increased deficiency in the element *time* for the absorption of the caloric in the tube compartment.

These conclusions might seem to militate against the results and previous reasonings derived from enlarged grates and extended surfaces, exposed to the radiating caloric in other boilers. A little examination and reflection will, however, dissipate the apparent contradiction.

I stated, at the commencement of this investigation of the properties of the locomotive boiler, that strict analogy between it and others ceases with the production of heat. In all boilers supplying steam to fixed engines, the steam consumed by the engine—which is a determinate quantity—governs the rate

of its generation in the boiler, and space permits the adoption and use of boilers of such dimensions as to endow them with a *power* of generating both heat and steam greatly in excess over the demands of the engine. This *surplus power of boiler* permits the employment of the controlling agency of the damper, which not only regulates the generation of the heat, but also detains that heat about the boiler, and times its departure from it.

The object of the locomotive engine is speed. Its tractive power has two limits; the force of adhesion to the rails, and the supply of steam. Its maximum load being determined by the amount of adhesive force, the mechanical power of the engine depends on the pressure of the steam; and the velocity of the engine depends on the quantity of steam, at that pressure, which the boiler can furnish in a given time. Hence it is that the power of a locomotive engine has been said by writers on the subject *to reside in the boiler;* and so long as the boiler is inadequate to supply any more steam than is barely sufficient to overcome the load determined by the adhesive force, or smaller loads at higher velocities, the expression is true in fact, though it appears to me to be neither a logical nor a philosophical expression, as it is only true so long as the evaporative power of the boiler is insufficient for, or merely balances the demands of the engine. Supposing the boiler to possess a power of furnishing steam to the engine in excess over its demands, the expression ceases to apply; and until the boilers of locomotive and of all other engines do possess this *power in excess,* they must inevitably continue to be prodigal of heat; for it is only through *an excess in the power of generating heat and steam over the demands of the engine,* that we can economize fuel; it is only by this *surplus power* that sufficient *time* can be allowed for each particle of heated matter to transmit its burthen of caloric to the water, before it quits the boiler.

It will be observed, that the Table exhibits the particulars of the locomotive combustion, in M. de Pambour's experiments, *coke* being the combustible, which has been compared with that from *coal* in all the other boilers. I have extracted from Mr. Wood's third edition of his Work on Railways, page 333, his own experiments on evaporation from a locomotive, *coal* being the combustible, in an engine termed by him the "improved Killingworth," all the elements of which will be found decomposed, Experiment XVI. These, so far as I can ascertain, are the only recorded facts of locomotive evaporation with coal as fuel; and though the boiler of the "improved Killingworth engine" is evidently one not fitted for railway engines in general, (nor is it recommended

as such by Mr. Wood,) yet the facts, coming from so respectable a source, are entitled to credence, and are highly useful as illustrating the calorific value of coke and coal as combustibles in the locomotive.

Prodigal as the other locomotives have seemed to be, this boiler exhibits an appetite for fuel which a near proximity to a coal-pit alone could satisfy; nevertheless, its voracity does not appear to me to be much if at all greater than other locomotive boilers, whose *apparent* evaporation and economy are superior, chiefly because they are supplied with the stronger and more condensed food of coke. In my former paper I stated the necessity of diminishing the results of evaporation obtained from coke, in the locomotive boilers, or raising those from coal in the other boilers, that the comparison between them might be made on equal terms. Mr. Wood's experiments on the "improved Killingworth boiler" tend to confirm me in not having over-rated the strength of coke in my former estimate, as the evaporation obtained by him is 4.4 lbs. of water by 1 lb. of coal, and that from coke 6.2 lbs. in the other engines, (from the temperature of the water in the tender,) being a difference in favour of coke of 40 per cent.—Though Mr. Wood's boiler, from its dimensions and proportions of parts, would be considered inferior in its economic qualities, compared with the other locomotive boilers examined, I do not think it much so, and it possesses some advantages which the others have not; and, though I find M. de Pambour, page 349, quoting from Mr. Wood, that "a ton of coals of good quality produces a little more evaporation than the same weight of good coke," I feel fortified by the positive fact now adduced from experiments by Mr. Wood himself, in adhering to my former conclusion, and I have, consequently, in all the foregoing comparisons, reduced the evaporative product obtained from the locomotives by 20 per cent., leaving the precise facts of the experiments in the Table*.

* When writing my paper of last session, I was not aware that any doubt of the fact of the superior strength of coke over coal existed; and seeing that every day practice and experience in various arts, and under steam-boilers also, verified my own opinion, the only question in my mind was the degree of difference in calorific value of the two combustibles, and I contented myself by assigning $\frac{1}{5}$th in favour of coke, which I then thought, and still think, too low. It seems that Smeaton found the effect of coke to be $\frac{5}{6}$ths that of an equal weight of the same coals from which the coke was made—66 lbs. of coke being obtained from 100 lbs. of coal, (Farey on the Steam-Engine, page 172,) but it does not appear that he made any alteration in his grate to suit it for coke, and without such adaptation the experiment tells nothing. I have found, by proper management, 75 lbs. of coke equal in effect to 100 lbs. of the self-same coal

AN INVESTIGATION

OF

THE RELATIVE TIME DURING WHICH THE PRODUCTS OF COMBUSTION, FROM EQUAL WEIGHTS OF FUEL, CONTINUE IN OPERATION ON EQUAL AREAS OF THE SURFACE OF THE BOILERS; WITH AN ESTIMATE OF THE QUANTITY AND INTENSITY OF THE HEAT APPLIED TO THEM.

The structure of the parts, and the mode of setting a boiler, occasion the heat applied to it to travel greater or less distances, and to pass over very unequal extents of surface, in equal or unequal times. The distance travelled I shall consider as determined by the length of the circuit which the heat is compelled to traverse from the grate till it quits the boiler. The time in which it performs the circuit, is the period of the duration of a particle of heat about the boiler, and is the first question to be considered.

from which the coke was made, by actual practice on many tons during several weeks of work. Mr. Pellatt's mode of burning coke exhibits, in a far more perfect manner than any steam-boiler can do, the relative calorific value of coke and coal. The space within his glass pot furnace gives abundant room for the combination of air with the gaseous products; the flames are not extinguished by comparatively cold surfaces like those of a boiler, which, after inflammation, reduce them back again into smoke; the heat requisite for perfect combustion is always present; and his furnaces are particularly favourable to the development of all the power of coal; yet he finds common gas coke to be superior to coals in heating power by 25 per cent.; and gas coke is stated by M. de Pambour to be found inferior to Worsley coke by $12\frac{1}{2}$ per cent., which no one acquainted with coke will doubt—thus exhibiting an excess over coal by $37\frac{1}{2}$ per cent. from good oven coke. Coke may be defined to be the concentrated essence of coal; it has been deprived of its weaker calorific elements; it consists chiefly of carbonaceous matter, and must, necessarily, give out a much greater quantity of heat than an equal weight of coal. If the results of locomotive practice be such as have been presented by M. de Pambour and Mr. Wood, (though not confirmed by the latter gentleman's experiments above quoted,) they merely shew that a locomotive furnace and boiler are ill adapted to develope the power either of coke or coal; and they simply prove, that in the way in which coke and coal are submitted to combustion, and their heat to absorption in that boiler, the loss on the whole heat generated is proportionally much greater on coke than coal. The products of the combustion of coke (unincumbered with the caliginous particles attending that of coal, and occupying much less space than flame) escape more rapidly and freely through the tubes than the more gaseous and voluminous products of coal, from which they have previously been purified. That the heat from coke is more intense than that from coal is a matter of notoriety, and the fact (if it be a fact) of coal having produced as great an effect as coke in locomotives probably arises from the longer detention of the flame and heat of the former within the boiler, because, from its greater volume and expansion *it cannot get out* as fast as the heat of coke, which may have led to the hasty and fallacious conclusion, that coke is the weaker combustible.

The rate of combustion, or the time in which a pound of fuel is burnt, seems to me to be the best practical measure of the velocity of the products of that combustion about a boiler. The mind readily apprehends, that if a pound of coal be consumed under one boiler, in half the time that it is consumed under another, the velocity of the current must be twice as rapid in the one case as in the other; but if the velocity be expressed in feet per minute, or miles per hour, no information is conveyed of an appreciable or practical nature; nor does that expression reach the source or origin of the current, viz., the rate of combustion. The real velocity of the current of heat is not determinable from this datum of the rate of combustion, and it is very different in different parts of the same boiler, nor can it be accurately ascertained without some fitting instrument; and all that has been written about the density and rate of motion of the heat in a locomotive boiler—based on calculations of its velocity from that of the steam escaping from the blast pipe—strikes me as utterly worthless in a practical sense, as giving no knowledge, and leading to no useful end; and such calculations would, I am convinced, be found very wide of the truth if tested by a meter *.

I shall simply attempt to determine the relative, not the positive, times occupied by the heat in operating on the different boilers under review, and state the result in terms of the ratios which these times bear to each other. In endeavouring, therefore, to estimate the value of *time* as an element influencing evaporative results, I shall consider it to be referable—

1st. To the rate of combustion.

2d. To the distance passed over by the products of combustion before they quit the boiler.

3d. To the time in which the heat traverses the boilers.

4th. To the period of the duration of the heat about equal areas of surface.

It is necessary to state that the rate of combustion now spoken of, is not the rate reckoned on the square foot of grate, but the consumption of fuel in an unit of time under *one* boiler of each class. It has, therefore, been necessary to reduce the whole weight of fuel burnt in a given time, in the several experiments, to its equivalent under *one* boiler. The evaporative results are not affected thereby, but remain strictly comparable with the results arising out of the present investigation, and the facts which appear in Table II., as data required for this analysis, are all derived from particulars given in Table I.

* Wood on Railways. Third Edition, page 508.

Table II.

Rate of combustion in one Boiler.			Circuit of the Heat.	Heated surface.
Boilers.	Pounds burnt per minute.	Time in burning 1 lb.		
	lbs.	seconds.	ft.	sq. ft.
Cornish.........	1.361	44.08	155.00	961.66
Warwick.......	1.566	38.31	50.66	151.66
Mean Wagon..	3.620	16.57	72.50	342.81
Locomotive....	9.295	6.45	7.00	334.56

Proposition 1. The velocities of the current of heated matter through each boiler, will be to one another directly as the rates of combustion, and inversely as the time in which equal weights of fuel are burnt. Using the latter measure, it appears that the respective velocities are,

Locomotive to the Cornish as 44.08 to 6.45, or 6.835 to 1.
Ditto Warwick 38.31 to 6.45, or 5.939 to 1.
Ditto Mean wagon 16.57 to 6.45, or 2.569 to 1.

Proposition 2. The distances passed over by the heat before it quits the boiler, are to each other directly as the circuits of the boilers: thus the

Locomotive is to the Cornish as 7 to 155.00, or 1 to 22.142.
Ditto Warwick as 7 to 50.66, or 1 to 7.237.
Ditto Mean wagon as 7 to 72.50, or 1 to 10.357.

Proposition 3. The times in which the surface of the several boilers is traversed by the heat, will be to each other, as the products of the ratios of the velocities of the current, or rates of combustion, multiplied into the ratios of the lengths or circuits travelled: thus the

Locomotive is to the Cornish as $6.835 \times 22.142 = 151.34$ to 1.
Ditto Warwick as $5.939 \times 7.237 = 42.98$ to 1.
Ditto Mean wagon as $2.569 \times 10.357 = 26.60$ to 1.

These last found sums truly represent the difference in the periods occupied by the passage of a particle of heat from the grate, till it quits the boilers; they consequently represent the difference in the periods of duration about the boilers of the products of combustion from equal weights of fuel; and we see that the heat of a pound of fuel remains in operation $151\frac{1}{2}$ times in the Cornish, 43 times in the Warwick, and $26\frac{1}{2}$ times in the mean wagon experiments longer than it

remains in the locomotive boiler. In like manner the mutual ratios of the duration of the heat about the Cornish and other boilers respectively are exhibited.

During, however, the periods in which the heat thus acts upon the boilers, it has spread itself over very varying extents and qualities of surface. It issues from the locomotive after travelling only 7 feet; but, in that length, it has passed through 96 tubes *, in as many streams or volumes, and communicated caloric during its transit, to $334\frac{1}{2}$ square feet. In the other boilers, the heat makes its circuit in one unbroken volume, it visits each portion of the boiler in succession, and it finally escapes in the same unbroken volume †. Though, therefore, we have found as above, the ratios of the periods of the duration of the heat in the several boilers, we have yet to find the relative time occupied by it in giving off its caloric to *equal portions* of *surface.* This is the second question to be considered, and is very easily solved.

Proposition 4. The heated areas of the boilers are to one another respectively, as follows: the

Cornish is to the Locomotive as		961.66 to 334.56, or 2.874 to 1.
Warwick	ditto	151.66 to 334.56, or 0.453 to 1.
Mean wagon	ditto	342.81 to 334.56, or 1.024 to 1.

Proposition 5. The periods of the duration of the heat about equal areas of surface, in the different boilers, will be to each other as the products of the ratios of the velocities of the current, or rates of combustion, multiplied into the ratios of the respective surfaces exposed to absorb the heat: and the

Cornish is to the Locomotive as		$6.835 \times 2.874 = 19.64$ to 1.
Warwick	ditto	$5.939 \times 0.453 = 2.69$ to 1.
Mean wagon	ditto	$2.569 \times 1.024 = 2.63$ to 1.

Thus we find that the heat from equal weights of coal acts upon equal areas during 1 minute in the locomotive, and during 2.63, 2.69, and 19.64 minutes

* The average number in the boilers experimented upon by M. de Pambour.

† Though in the Cornish, and such of the other boilers as have internal flues, the heat is *split,* during a portion of its progress, into two currents, the latter unite before quitting the boiler, and numberless experiments in setting these boilers have proved the effect to be the same, whether having what is termed a *wheel,* or a *split* draft. I have, therefore, for the sake of simplicity, spoken of the heat making the circuit of these boilers, "*in one unbroken volume.*"

respectively in the other boilers. These then may be properly termed the *relative periods* of *calorific action*, arising out of the structure and practice of each class of boiler.

The truth of these results may be confirmed by another process. It is the same thing to burn, as in the Cornish boiler, one pound of coal in 44.08 seconds, and apply the heat to 961.66 square feet of boiler, as to burn 44.08 lbs. in one second of time, and apply the heat to 44.08 times as great a surface. We should thus find that 42389 square feet would be the area corresponding with that increased rate of combustion for the Cornish boiler. In like manner 2157 square feet would be the equivalent surface for a rate of combustion in the locomotive increased by 6.45 times. The quotient of 42389 ÷ 2157 is 19·64 as above, and represents precisely the difference in time during which the heat elicited from a pound of coal remains in operation under equal surfaces in the Cornish and locomotive boilers respectively.

Were the respective surfaces and structure of boilers of an identical nature, and the practice in each case equally skilful, surface and time would be convertible terms, and ratios obtained by the foregoing process would express with precision the additional areas requisite to be given to one boiler, in order that its evaporative economy should correspond with that of any other boiler compared with it; and though we are ignorant of the heat-transmitting powers of plates of metal of varying thicknesses, as also of the effect of their position in the arrangement of the parts of a boiler; nevertheless, by this method of analysis, we can make ourselves acquainted with the fact, and with the amount of any deficiency in the element *time* by the comparison of inferior with superior boilers; and we are, by these means, informed of the relative degree in which that element is possessed by the different boilers under review.

We know, however, that boilers in every respect alike as to structure, strength, proportion of parts, &c., yield very different results from different treatment, as shewn in numerous instances in Table I.; so that these indications of the effect of *time* must be viewed simply in the light of so many facts attending the comparative practice of the several classes of boiler in the experiments under examination, and not as determinate of any law or rule by which the period of calorific action, or the extent of surface requisite for obtaining equal effects from equal weights of fuel, *in all forms and conditions of boiler*, are governed. There can be no question but that *time*, in some amount, is indispens-

able for the transmission of heat to water through the vessel which contains it —whatever be the structure or strength of that vessel; but it is equally certain that the quality of the fuel, the intensity of the combustion, the nature and strength of the material of the vessel, the form and arrangement of its parts, the proportion of one part to another, and other causes exercise also no inconsiderable influence over evaporative results: I thought it, therefore, better to separate this more analytical, from the more purely practical part of the subject, than to risk confusion by involving the abstract question of time and its influence, in the consideration of the effects produced by other phenomena on the performance of the boilers.

The following Table exhibits, in juxtaposition, the rates of combustion, the evaporative results, the ratios now found of the periods of calorific action, with the gain and loss of effect, by which the influence due to *time*, on the *economy* of heat may be accurately appreciated.

Table III.

BOILERS.	Rate of combustion.	Water evaporated by 1 lb. of coal.	Ratios of the total duration of the heat in the boilers from equal weights of coal	Ratios of the duration of equal amounts of heat, about equal areas of the boilers.	Loss of evaporative effect, the Cornish results being unity.	Gain of evaporative effect, the Locomotive results being unity.
	1 lb. in seconds.	212°. lbs.	Locomotive, Unity.	Locomotive, Unity.	Per cent.	Per cent.
Cornish......	44.08	11.82	155.00	19.64	...	104.85
Warwick.....	38.31	10.32	42.98	2.69	12.69	79.02
Mean Wagon	16.57	8.83	26.60	2.63	24.45	53.03
Locomotive..	6.45	5.57	0.00	0.00	51.18	...

Having thus ascertained the relative periods of the total duration of the heat about the boilers, and about equal areas of the entire surface, which appear so vitally to affect economy, two other important phenomena press themselves on the attention, as having an especial bearing on the *durability* of the boilers; viz., the relative quantity, and the relative intensity of heat given off to those portions of the boilers which are exposed to the direct action, or radiating caloric of the fire. As data for this investigation it is necessary to extract from Table I. the areas of the radiant surfaces, and grates.

Table IV.

1 BOILER.	Area exposed to radiant heat.	Area of the Grates.
	Sq. ft.	Sq. ft.
Cornish.........	35.33	23.66
Warwick.......	35.66	23.50
Mean Wagon	39.82	20.87
Locomotive....	41.47	7.00

Proposition 6. The quantities of heat, generated in equal times, are directly as the rates of combustion before found, Prop. 1.

Proposition 7. The areas of the boilers exposed to the radiating caloric are to one another as follows; the

Locomotive to the Cornish as 41.47 to 35.33, or as 1 to 0.851.
Ditto Warwick as 41.47 to 35.66, or as 1 to 0.860.
Ditto Mean Wagon as 41.47 to 39.82, or as 1 to 0.960.

Proposition 8. The quantity of heat supplied to equal areas of these portions of the boilers, will be as the products of the ratios of the rates of combustion multiplied into the ratios of the radiant surfaces; thus the

Locomotive is to the Cornish as $6.835 \times 0.851 = 5.81$ to 1.
Ditto Warwick as $5.939 \times 0.860 = 5.10$ to 1.
Ditto Mean Wagon as $2.569 \times 0.960 = 2.46$ to 1.

These sums indicate that in equal periods the locomotive fire box is supplied with 5.81 times more heat than an equal area of the Cornish, and 5.10 and 2.46 times more heat than the Warwick and mean wagon boilers; and they would express the relative force of calorific action on each square foot, or on equal areas of the surfaces under review, provided the fuel were burnt on grates of equal size; but the intensity of the calorific action—by which the durability of the boilers is principally affected, as also the product in steam from the radiant surfaces—must be measured in a different manner.

The *quantity* of heat supplied to any boiler would not affect the material of which it is composed any the more, whether that quantity or volume were greater or less, provided its *temperature* or intensity remained the same. This

intensity varies greatly in the different boilers. We have seen that on the grate of the locomotive 6.835 times more heat is generated in equal periods than on the Cornish grate; but the grate of the locomotive has only 7 feet area, whilst that of the Cornish has 23.66 feet; and we know that nearly 7 times as much fuel cannot be burned in equal times off a grate less by two thirds than another grate, without the accelerated combustion being accompanied by a very considerable elevation of temperature in the products of combustion. The *intensity* of that combustion must, therefore, be found before its intensity of action on the surfaces exposed to it, can be ascertained.

Proposition 9. The areas of the grates are to one another as follows; the

Locomotive is to the Cornish as		7 to 23.66, or 1 to 3.380.
Ditto	Warwick	7 to 23.50, or 1 to 3.357.
Ditto	Mean Wagon	7 to 20.87, or 1 to 2.981.

Proposition 10. The relative intensity of the combustion of the fuel will be as the products of the ratios of the areas of the grates multiplied into the ratios of the rates of combustion upon those grates; thus the

Locomotive is to the Cornish as		$6.835 \times 3.380 = 23.10$ to 1.
Ditto	Warwick	$5.939 \times 3.357 = 19.93$ to 1.
Ditto	Mean Wagon	$2.569 \times 3.727 = 7.65$ to 1.

As a proof that these last ratios are correct exponents of the relative force or intensity of combustion in equal times, they will be found to coincide precisely with the difference in the weights of coal burnt on each square foot of grate per hour, as shewn in Table I., column 20.

PROOFS.

79.3 lbs. coal burnt on each square of grate per hour, in the locomotive $\div$ 3.4 lbs., the rate of the Cornish $= 23.03$ ratio.

79.3 lbs. $\div$ 4 lbs.	the rate of the Warwick	$= 19.8$ ratio.
$79.3 \div 10.4$	Mean Wagon	$= 7.6$ ratio.

By involving these ratios with those of the respective areas of the radiant

surface, the *intensity of the calorific action* on equal areas, in equal times, will be made manifest.

PROPOSITION 11. The relative intensity of calorific action on the surfaces exposed to radiant heat, will be, as the products of the ratios of the intensity of combustion on the several grates, multiplied into the ratios of the areas of the radiant surfaces; and the

Locomotive is to the Cornish as $23.10 \times 0.851 = 19.65$ to 1.
Ditto Warwick $19.93 \times 0.860 = 16.83$ to 1.
Ditto Mean Wagon $7.65 \times 0.960 = 7.34$ to 1.

The proofs of this solution of the problem will appear by the identity of the last ratios with the quotients of $23.10 \times \frac{35.33}{41.47}$; of $19.93 \times \frac{35.66}{41.47}$; and of $7.65 \times \frac{39.82}{41.47}$; being the respective ratios of fuel burnt, and of radiant surface between the locomotive and the three other boilers.

The results, arising out of the foregoing propositions as affecting the *durability* of the boilers to a great, and their *safety* to a certain extent are classified in

TABLE V.

BOILERS.	Ratios of the intensity of the combustion in the several boilers, to that in the Locomotive, each boiler unity.	Ratios of the intensity of calorific action on the parts exposed to radiant heat to that in the Locomotive, each boiler being unity.
	Ratios to Locomotive.	Ratios to Locomotive.
Cornish..................	1 to 23.10	1 to 19.65
Warwick.................	1 to 19.93	1 to 16.83
Mean Wagon	1 to 7.65	1 to 7.34
Locomotive............	...	...

I have used the phrase *intensity of calorific action* rather than intensity of heat or temperature, as these sums by no means express the difference in the degrees of the latter. I am not aware that the temperature of boiler fires has ever been ascertained pyrometrically or otherwise, nor do I very clearly see how such indications could be obtained by instruments; nor would any ascertained temperatures denote the effect of what I have termed *calorific action* on the

metal of the boilers. The intensity of that action is not referable to the temperature of the fire alone; it is modified by the distance of the fire from the surfaces exposed to it, in proportion to the squares of those distances; it is modified by the nature of the combustible used; by the nature of the particular gasses which impinge against the metal; by the force with which the radiant particles are thrown off from the grate; also, by the force with which the flames strike the absorbing surface; and I conceive the latter force to be infinitely more influential on the durability of an evaporative vessel, than that of the radiating caloric, as the temperature of flame is much more elevated than that of radiant heat.

Intensity of combustion is the effect of the velocity of the current of air upon the fire; and what I wish to convey by the phrase *intensity of calorific action*, is the joint force arising from the increased temperature, and increased velocity of the product of combustion; and the degrees of durability are the consequences of the effects produced by this force upon the material of the vessels. It is clear that the temperature of the heat in the fire-box of a locomotive is not pyrometrically eighteen times more elevated than that within the furnace of a Cornish boiler; nevertheless, the ratios found in Proposition 11 are facts as regards the relative *action* of the fires, and they are not bad approximate measures of the effects caused by the different systems of practice upon the durability of those portions of the boilers which are exposed to what is called radiant heat, or radiating caloric; a phrase which expresses a very inadequate idea of the severe action to which these surfaces are subjected.

The advantage of slow combustion will, by these investigations, have been rendered more evident than by considering its effect on economy alone; and the influence of *time* as an element concerned not only in the generation, but in the subsequent use of the heat, will be better appreciated.

Having exhibited the relative state in which the heat is found within the furnaces of the several boilers, it would be easy to shew its condition and relative intensity upon the communicative portions; but as a comparison has already been given of its duration about equal areas of the entire surface, I conceive the influence of *time* will be sufficiently understood without pursuing the investigation further.

Table I.

No. of experiment.	Place of experiment.	Nature of Coals used.	Form of the boilers.	No. of boilers in use.	Length.	Breadth.	Diameter. Outside.	Diameter. Fire-tube.	Mean depth of side, or external flues.	Area of bottom flues.	Area of side, or external flues.	Area of internal flues.	Total area of heated surface.	Surface exposed to radiant heat.	Surface exposed to communicative heat.	Length of circuit made by the heat in one boiler.	Area of the grates.
					PARTICULARS OF THE BOILERS.												
	Cornwall.	†			ft.	ft.	ft. in.	ft. in.	ft. in.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	ft.	sq. ft.
I.	Huel Towan	W	Cyl.	3	36	...	6.0	4.0	...	...	1243	1357	2600	114	2486	152.	72.0
II.	United Mines	W	Cyl.	3	2. 36 1. 40	...	6.4	4.4	...	...	1646	1524	3170	98	3072	158.	70.0
II.*	Mean of Exp. I. & II......	W	Cyl.	3	36.66	...	6.2	4.2	...	...	1445	1440	2885	106	2779	155.	71.0
III.	East Crinnis	W	Cyl.	3	2. 34 1. 36	... ...	2. 6.9 1. 7.0	2. 4.0 1. 4.5 by 3.5	...	...	1178	1322	2500	57	2443	152.33	37.5
IV.	BinnerDowns	W	Cyl.	2	30	...	6.0	4.	...	...	686	754	1440	76	1364	132.	48.0
V.	Warwick.....	S.	Wag	3	1. 15.0 2. 12.5	1. 6.0 2. 5.0	...	...	2.6	215.0	240.0	none.	455.0	107.0	338.0	50.66	70.5
VI.	Clithero......	L.	Wag	1	20.0	5.5	...	...	2.9	110.0	120.0	90.0	320.0	23.62	296.38	91.0	17.6
VII.	Ditto	L.	Wag	1	20.0	5.5	...	...	2.9	110.0	120.0	90.0	320.0	35.43	284.56	91.0	20.25
VIII.	Preston	L.	Wag	1	13.5	8.0	...	...	3.	108.0	108.0	81.0	297.0	46.85	250.15	70.0	27.75
IX.	Ditto	L.	Wag	1	13.5	8.0	...	...	3.	108.0	108.0	81.0	297.0	46.85	250.15	70.0	27.75
X.	Ditto	L.	Wag	1	13.5	8.0	...	...	3.	108.0	108.0	81.0	297.0	46.85	250.15	70.0	27.75
XI.	Albion Mills	N.	Wag	1	16.0	6.0	...	...	5.6	70.0	236.5	215.0	521.5	35.0	486.5	70.0	24.5
XII.	London	N.	Wag	2	15.0	5.5	...	...	2.6	165.0	180.0	none.	345.0	31.5	313.5	56.0	22.66
XIII.	Ditto	N.	Wag	2	15.0	5.5	...	...	2.6	165.0	180.0	none.	345.0	52.5	292.5	56.0	40.50
XIII.*	Mean of experiments VI. XIV.	L. N.	Wag	1	36.66	6.5	...	...	$3.1\frac{1}{2}$	118.0	145.06	79.75	342.81	39.82	302.98	72.5	26.09
XIV.	Long Benton	N.	Circ.	2	...	...	1. 12. 1. 13.6	...	4.3	142.0	317.0	none.	459.0	71.0	388.0	52.8	35.10
XV.	Manchester and Liverpool Railway	Coke.	Loc.	1	7.0	...	...	Fire-box. 41.47	...	...	...	Tubes. 293.11	334.56	41.47	293.11	7.0	7.03
XVI.	Killingworth	Coals.	Loc.	1	10.0	...	...	22.56	...	...	...	101.5	124.06	22.56	101.5	...	12.90
	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15	16

† W. indicates Welsh; S. Staffordshire; L. Lancashire; N. Newcastle.

Table I.—continued.

Particulars of the combustion.						Temperature of the water entering the boilers.	Pressure of the steam above the atmosphere.	Particulars of the evaporation from the initial temperature of the water.								
No. of experiment.	Duration of the experiment.	Total weight of fuel burnt.	Weight burnt per hour.	Weight burnt per square foot of grate per hour.	Weight burnt per square foot of heated surface per hour.			Total pounds of water evaporated.	Total cubic feet evaporated.	Pounds evaporated per hour.	Cubic feet evaporated per hour.	Pounds evaporated per 1 lb. of fuel.	Cubic feet evaporated by 112 lbs. of fuel.	Pounds of fuel evaporating 1 cubic foot of water.	Pounds of water evaporated by the products of combustion per square foot of grate per hour.	Pounds of water evaporated per square foot of heated surface per hour.
	ho. min.	lbs.	lbs.	lbs.	lbs.	o	lbs.	lbs.	cub. ft.	lbs.	cub. ft.	lbs.	cub. ft.	lbs.	lbs.	lbs.
I.	24 33	5003	203.78	2.83	0.078	93.8	49.4	52937	847.0	2156.31	34.82	10.58	18.96	5.90	29.94	0.829
II.	24	6872	286.33	4.09	0.093	96.0	35.0	72072	1153.15	3003.0	48.04	10.48	18.79	5.95	42.90	0.977
II.*	24 16½	5937	245.30	3.46	0.085	94.9	42.2	62504	1000.07	2579.65	41.43	10.53	18.87	5.92	36.42	0.903
III.	11 27	3005	262.44	7.00	0.104	...	...	...	...	...	...	...	...	...	...	...
IV.	25 3	5661	222.00	4.62	0.154	...	...	...	...	...	...	...	...	...	...	...
V.	10 30	2961	282.00	4.00	0.019	93.0	2.5	27156	434.5	2586.31	41.38	9.17	16.44	6.81	36.68	5.684
VI.	20 25	4144	203.03	11.53	0.634	44.0	5.0	23674	378.78	1160.0	18.55	5.71	10.23	10.94	65.90	3.625
VII.	12 25	2016	162.44	8.02	0.507	44.0	5.0	16775	268.40	1351.73	21.62	8.32	14.91	7.51	66.75	4.224
VIII.	9 19	2576	276.69	9.97	0.931	76.0	4.0	19312	309.0	2074.3	33.17	7.49	13.43	8.33	74.74	6.984
IX.	10	2576	257.60	9.27	0.867	80.0	4.0	21875	350.0	2187.5	35.00	8.49	15.21	7.36	78.82	7.360
X.	8	2638	329.75	11.88	1.110	74.0	4.0	22125	354.0	2765.62	44.25	8.38	15.02	7.45	99.65	9.311
XI.	10	4030	403.00	16.44	0.772	100.25	2.5	34750	556.0	3475.0	55.60	8.62	15.45	7.24	141.83	6.663
XII.	19	5512	290.00	12.79	0.840	101.50	2.5	38625	618.0	2032.9	32.52	7.00	12.55	8.91	89.71	5.891
XIII.	22 22	5953	250.13	6.17	0.725	96.5	2.5	48251	772.24	2157.92	34.53	8.10	14.52	7.70	53.28	6.254
XIII.*	13 56	3680	271.58	10.75	0.798	77.0	3.68	28173	450.81	2150.62	34.40	7.76	13.91	8.18	83.83	6.289
XIV.	1	714	714.00	20.34	1.55	152.0	1.5	5625	90.0	5625.0	90.0	7.87	14.11	7.93	160.25	12.250
XV.	1 38	911	557.75	79.33	1.66	60.0	50.0	5664	90.62	3467.75	55.48	6.21	11.14	10.05	493.27	10.360
XVI.	1	586.88	586.88	45.49	4.73	60.0	...	2620	41.92	2620.0	41.92	4.46	8.00	14.00	203.10	21.118
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32

TABLE I.—CONTINUED.

No. of experiment.	PARTICULARS OF THE EVAPORATION FROM WATER AT THE TEMPERATURE OF 212°.									PARTICULARS OF THE PROPORTIONS OF HEATED SURFACE TO FUEL BURNT, AND WATER EVAPORATED.					
	Total pounds of water evaporated.	Total cubic feet evaporated.	Pounds evaporated per hour.	Cubic feet evaporated per hour.	Pounds evaporated by 1 lb. of fuel.	Cubic feet evaporated by 112 lbs. of fuel.	Pounds of fuel evaporating 1 cubic foot of water.	Pounds of water evaporated by the products of combustion per square foot of grate per hour.	Pounds of water evaporated per square foot of heated surface per hour.	Square feet of heated surface to 1 square foot of grate.	Square feet of heated surface per lb. of fuel burnt per hour.	Square feet of heated surface per lb. of water evaporated per hour from its initial temperature.	Square feet of heated surface per lb. of water evaporated per hour from 212°.	Square feet of heated surface per cubic foot of water evaporated per hour from its initial temperature.	Square feet of heated surface per cubic foot of water evaporated per hour from 212°.
	lbs.	cub. ft.	lbs.	cub. ft.	lbs.	cub. ft.	lbs.	lbs.	lbs.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.
I.	59510	952.16	2424.04	38.78	11.89	21.31	5.25	33.66	0.932	36.11	12.75	1.205	1.072	74.67	67.04
II.	80866	1293.85	3369.41	53.91	11.76	21.08	5.31	48.13	1.096	43.88	10.72	1.022	0.911	63.94	56.98
II.*	70188	1123.0	2896.72	46.34	11.82	21.19	5.28	40.89	1.014	39.99	11.73	1.113	0.991	69.30	62.01
III.	...	...	...	...	...	...	...	...	...	66.66	9.52	...	...	...	...
IV.	...	...	...	...	...	...	...	...	...	30.00	6.48	...	...	...	...
V.	30558	488.93	2910.29	46.56	10.32	18.50	6.05	41.28	6.396	6.45	1.61	0.1759	0.1563	10.99	9.77
VI.	27910	446.56	1367.46	21.87	6.73	12.06	9.27	77.69	4.273	18.18	1.57	0.275	0.234	17.25	14.63
VII.	19741	315.85	1590.70	25.45	9.79	17.54	6.38	78.55	4.970	15.80	1.97	0.236	0.201	14.80	12.57
VIII.	22075	353.36	2371.10	39.00	8.56	15.36	7.28	85.44	8.000	10.70	1.07	0.143	0.124	9.00	7.82
IX.	24913	398.60	2491.30	37.95	9.67	17.33	6.46	89.77	8.388	10.70	1.15	0.135	0.119	8.48	7.45
X.	25337	405.39	3167.12	50.67	9.60	17.21	6.50	114.13	10.663	10.70	0.900	0.107	0.093	6.71	5.86
XI.	38846	621.53	3884.60	62.15	9.63	17.27	6.48	158.55	7.448	21.28	1.294	0.150	0.134	9.38	8.39
XII.	43117	689.88	2269.35	36.30	7.82	14.03	8.00	100.14	6.577	15.22	1.189	0.169	0.152	10.60	9.50
XIII.	54116	865.85	2420.21	38.72	9.09	16.29	6.87	59.75	7.015	8.51	1.379	0.159	0.142	10.00	8.91
XIII.*	32006	512.11	2445.23	39.01	8.86	15.88	7.15	95.50	7.166	13.88	1.315	0.171	0.149	10.77	9.39
XIV.	5980	95.68	5980.0	95.68	8.37	15.00	7.46	170.36	13.02	13.08	0.642	0.0816	0.0767	5.10	4.79
XV.	6569	105.10	4030.0	64.48	7.21	12.92	8.66	573.25	12.04	47.59	0.581	0.096	0.080	6.02	5.03
XVI.	3038	48.60	3038.0	48.60	5.17	9.27	12.07	235.50	24.48	9.61	0.211	0.047	0.040	2.95	2.55
	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47

RESULTS of an ANALYSIS of the influence exerted on the Evaporative Economy, and Durability of the Boilers, by the TIME occupied in generating and employing the HEAT.

COMPARATIVE ECONOMY.								DURABILITY.	
No. of experiment.	BOILERS.	Rate of combustion per boiler.	Water evaporated from 212° by 1 lb. of coal.	Ratios of the total duration of the heat in the boilers, from equal weights of coal; the locomotive, unity.	Ratios of the duration of equal amounts of heat, about equal areas of boilers.	Comparative loss of evaporative effect, the Cornish results being unity.	Comparative gain of evaporative effect, the locomotive results being unity.	Ratios of the intensity of combustion in the several boilers to that in the locomotive, each boiler being unity.	Ratios of the intensity of the calorific action on the parts exposed to radiant heat, to that in the locomotive, each boiler being unity.
		1 lb. coal in seconds.	Water. lbs.	Locomotive Unity.	Locomotive Unity.	Loss per cent.	Gain per cent.	Ratios to locomotive.	Ratios to locomotive.
II.*	Cornish	44.08	11.82	155.00	19.64	0.00	104.85	1 to 23·10	1 to 19.65
V.	Warwick....................	38.31	10.32	42.98	2.69	12.69	79.02	1 to 19.95	1 to 16.83
XIII.*	Mean Wagon..............	16.57	8.83	26.60	2.63	24.45	53.03	1 to 7·63	1 to 7.34
XV.	Locomotive................	6.45	5.57	0.00	0.00	51.18	0·00	0.00	0.00
		48	49	50	51	52	53	54	55

NOTES.

Experiments.

I.—See Mr. Henwood's paper, Transactions of the Institution of C. E., Vol. II. page 56. The additional dimensions of the boilers, not found in Mr. Henwood's paper, were afterwards obtained from him.

II.—The particulars of these boilers, which were carefully measured by the resident engineer, were supplied to me by Mr. John Taylor. The quantities of coal and water are reduced from 8 months to the consumption of 24 hours, from Table II. of my paper. Vol. II. p. 174.

III., IV.—See Mr. Henwood's paper, p. 56.

V.—This is the mean (reduced to 10½ hours, or the period of an actual day's work) of 6 complete months' registration of all the coal consumed, and water evaporated from my own boilers at Warwick, working a 26 horse steam-engine, and supplying a dye-house, wash-house, &c. The coal is the entire weight burnt off the grates, raking at night, and all waste included. The water was gauged from a rectangular reservoir, holding more than a day's consumption, and includes all waste, except that required to refill a boiler when cleaned, and a certain quantity which was blown out of each boiler every night. One of the three boilers was emptied every week, the water being very foul; at the same time the dust was cleared away from the flue bottoms, and the sides of the boilers were well scoured to remove the soot. This latter operation was effectually performed by dragging backwards and forwards a stuffed bag, covered on the outside with coarse woollen cards, and fitting pretty tight between the flue wall and the boiler. By numerous trials it was found that the incrustation of soot impeded the absorption of heat by the boilers (and consequently increased the consumption of fuel) more than the deposit within them, which was considerable, but never suffered to become indurated.

VI.—The sum of Experiments 2 and 3, Table I. of my former paper, page 171.

VII.—See Experiment 5. . . . ditto . . ditto . ditto.

VIII., IX., X.—See Experiments 6, 7, 8 ditto . . ditto.

XI.—Watt and Rennie, ann. 1786. (Farey on the Steam-engine, Vol. I. p. 511.)

XII.—The sum of Experiments 9 and 10, Table I. of my former paper.

XIII.—Ditto . . . 11, 12 and 13, . . ditto.

XIV.—Smeaton's Newcomen engine, an. 1772. (Farey on the Steam-engine, Vol. I. p. 173.)

XV.—The mean of 11 experiments, of which 9 are given in my former paper, Table III., p. 176. (Pambour on Locomotive Engines, pages 175. 320.)

XVI.—See Wood on Railways, 3d ed., pp. 333 and 521.

N.B.—The quantities of water in the columns of evaporation from 212° have been obtained from the real quantities which entered the boilers by the rule and table given in my former paper, pp. 178 and 179.

London, December, 1838. JOSIAH PARKES.

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Some of the new subjects in this edition consist of the works of

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TREDGOLD ON THE STEAM ENGINE, AND ON STEAM NAVIGATION.

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